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ABSTRACT

This resource paper on geographical spatial diffusion is part of a series designed to supplement undergraduate geography courses. Focusing on the unfolding of man's patterns over geographic space and through time, the paper provides the basic theoretical background of this new, rapidly growing area of geography. Following a short introductory section, chapter two outlines the various carriers and barriers to both physical and cultural diffusion. Carrier processes may take the form of expansion, relocation, hierarchical filtering, or contagious diffusion as with diseases. Barriers to diffusion may be physical or cultural, such as differences in languages or levels of technology. Since spatial diffusion takes place on many different scales, chapter three focuses on the various models of individual or micro-level diffusion, urban diffusion, regional diffusion, and macro-level (or national and international) diffusion. Chapter four discusses the frontiers of diffusion research. Also included is a list of further readings and illustrative references. (Author/DE)

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The Pennsylvania State University

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FOREWORD

The Resource Papers have been developed as expository documents for the use of both the student and instructor. They are experimental in that they are designed to supplement existing texts and to fill a gap between significant research in geography and readily accessible materials. The papers are concerned with important concepts in modern geography and focus on three general themes: geographic theory; policy implications; and contemporary social relevance. They are designed as supplements to a variety of undergraduate college geography courses at the introductory and advanced level. These Resource Papers are developed, printed, and distributed by the Commission on College Geography which is supported by a grant from the National Science Foundation. Single copies are mailed to all AAG members.

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SPATIAL DIFFUSION

I. Meshing Space and Time

Man and his works exist in Space *and* Time—a statement so banal that it hardly seems worth mentioning. But upon closer examination, this truism contains such conceptual richness and intellectual challenge that it forms the core idea of one of Geography's most exciting contemporary fields. The power of the statement lies in that second conjunction *and*: we are going to consider Man and his works in both Space *and* Time. This means that we can no longer think about spatial patterns and relationships in a simple static sense; and we must reject, as geographers and social scientists, an exclusive focus upon the temporal dimension. Man in Space *and* Time: this is the area of spatial diffusion, where *processes* are frequently the core of our concern as we try to grapple with problems of *spatial dynamics*.

It is not an easy area. Once you have picked your way through this Resource Paper, and go on to the additional readings, you are virtually on your own. The mechanisms of spatial diffusion are little understood, and there is much exciting work to be done at many points along the continuum from general theory to applied empirical study. The unfolding of Man's patterns over geographic space and through time is a fascinating thing to watch and study, and once you have thought about the processes at work in these fundamental dimensions of human existence you can never wholly return to "pre-diffusion" thinking. This, in itself, is crucial; for whether you plan to become a social scientist, or simply an informed and responsible citizen, the world of 2000 is desperately going to need men and women with a clear view and involved concern for Man's use of space over time.

II. Types of Spatial Diffusion: The Pieces in the Problem

Whenever we enter a new area of learning, we must acquire a body of simple but fundamental concepts and terms from which we can build more complicated structures and carry on more difficult discussions. At the beginning, two things are obvious. First, anything that moves across geographic space must be carried in some way. Second, the rate at which some things move over space will be influenced by other things that get in the way. Thus, as we begin to think about various types of spatial diffusion, we must consider the sorts of carriers and barriers that can enter a particular problem.

The Carriers . . .

Let us consider a very common type of diffusion problem in which an idea spreads through a group of people. We can think of a rumor running like wildfire through a student population, or perhaps an idea about farming moving through an agricultural area. Initially, only a few people will have the idea or rumor (Figure 1a), but soon the idea is communicated to friends and neighbors. The new knowers in turn tell their acquaintances (Figure 1b), and gradually the idea spreads through the population. We shall call such a process an expansion diffusion, for as an idea is communicated by a person who knows about it to one who does not, the total number of knowers becomes greater and greater through time.

Not all diffusion processes are of the expansion type. In many cases, an initial group of people or carriers will themselves move (Figures 2a and b), so that they are diffused through time and over space to a new set of locations. It is for this reason that we shall call this type of process relocation diffusion. The commonest example, of course, is that of migration, when groups of people move their residences from one place to another. The whole geography of early settlement in the United States can be regarded as the diffusion of new immigrants across the face of America. The process continues today. If we could take time-lapse movies from a geographic space laboratory located permanently over the United States, and run through half a century in five minutes, we could see a number of relocation diffusion processes going on simultaneously at different speeds and scales. A slow, but gathering tide of black people from the South moves to the cities of the North, while rural Midwesterners leave their farms and move to California and the big cities. Superimposed upon the slow processes of diffusion acting over decades are the faster seasonal flows of vacationers, diffusing to sun and snow in winter, and shore and lake in summer. Still faster movements on the film would be the rapid pulses of daily commuters from the dormitory doughnuts that surround our cities. Another, though aspatial, example of relocation diffusion is the familiar "passing the buck" in any large bureaucracy or organization. Here the actual responsibility for a decision is diffused from hand to hand—or from one in-tray to another!

Diffusion processes can also be considered in other terms. Suppose a disease is diffusing through a population by direct contact; that is, one person must actually touch another before the disease can be transmitted. Examples would be the venereal diseases that appear to be reaching epidemic proportions once again in many of the large cities. We call such diseases contagious, and the term has been borrowed to characterize all diffusion processes of this type. Almost by definition, contagious

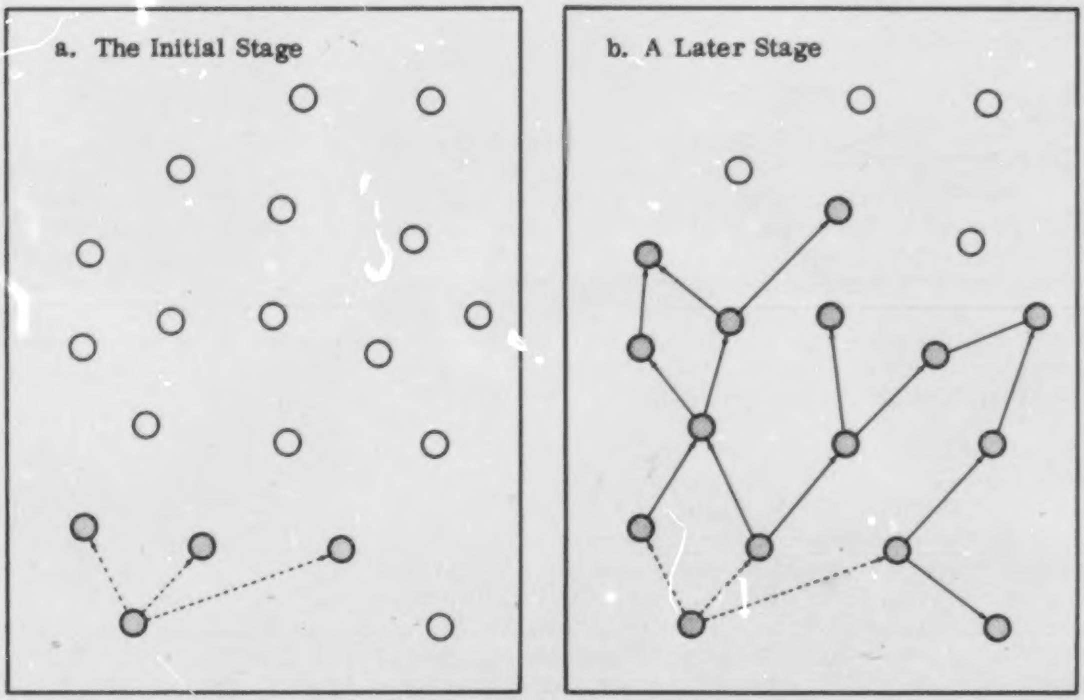
a. The Initial Stage
b. A Later Stage

FIGURE 1. Expansion Diffusion (adapted from Brown, 1968)

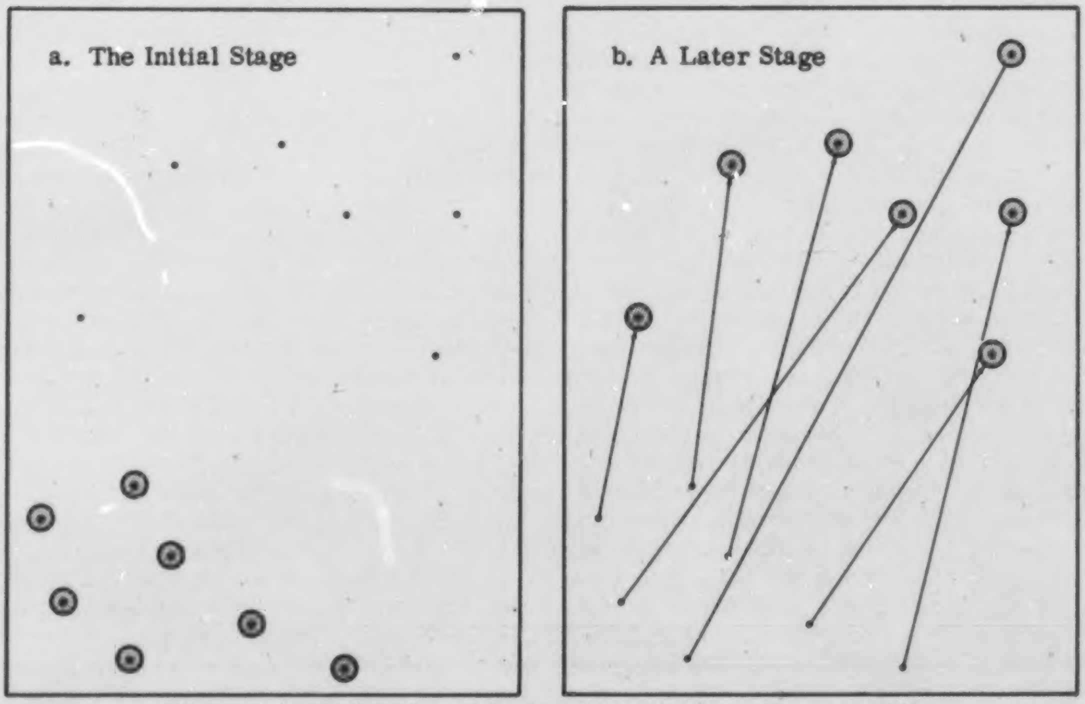
a. The Initial Stage
b. A Later Stage

FIGURE 2. Relocation Diffusion (adapted from Brown, 1968)

diffusion is strongly influenced by the frictional effect of distance. Many ideas and diseases are passed to people close to those who already have them.

Simple geographic distance is not always the strongest influence in a diffusion process, for some ideas and innovations seem to leap over many intervening people and places. Such leap-frogging usually characterizes processes of hierarchical diffusion, in which large places or important people tend to get the news first, transmitting it later to others lower down the hierarchy (Figure 3). Many clothing fashions, for example, originate in the major fashion centers of New York, Paris, and Rome, and then diffuse to other towns that form major regional nodes in Europe and the United States. From these the new skirt lengths, and other "vital statistics," diffuse to the provincial centers and so to the small towns in the rural areas. Few people have not observed the contrasts between fashions in the metropolitan areas and those in the rural towns which are due to this common diffusion lag. Similarly, at the personal level of diffusion, many farming innovations are adopted first by the larger, wealthier, and locally more important farmers in a region, and only then do the ideas trickle down the local social hierarchy to others in the area.

As we summarize the basic types of movement through space and time (Figure 4), it is obvious that diffusion processes are not always exclusively of one sort or another. For example, many expansion diffusions are of the contagious type. As an idea or an innovation spreads gradually outwards from a core area by a process of contagion, the sum total of adopters also grows. Our cities diffuse outwards by such a process, expanding along the urban fringe and main arterial routes. But expansion diffusion can also move through one of the many hierarchies that structure both geographic space and society. A cultural idea, for example, can cascade down the highbrow-lowbrow hierarchy, even as the lodges of many fraternal organizations trickle down to the small towns from the larger national and regional centers.

Similarly, some relocation diffusion processes may be considered in contagious terms. For many of these, distance becomes of crucial importance. Often a series of short steps are taken so that members of the initial group appear to explode outwards in a wave-like movement from the original location. A wave of combine harvesters diffuses northward each year across the Great Plains, each operator moving north in a series of short steps from one job to another until the harvest is finished in Canada. Within urban areas, many of the ghettos seem to have grown by people relocating their residences, but the diffusion outward is nearly always in a contagious fashion, with new residences locating close to those of the cultural group. However, most relocation diffusion seems to be of a hierarchical nature, as people and institutions move up and down the layered structures characterizing much of modern life. The diffusion of academic talent, for example, is largely of a hierarchical nature. Academic musical chairs does not take place at one common level but diffuses intellectual talent upward and downward to maintain and reinforce the very structure that channels and guides the movement.

It is clear from these examples that most diffusion processes are not simple and do not fall cleanly and neatly into distinct types. In many problems, several modes of diffusion may operate simultaneously and in changing intensity. For example, the diffusion of radio broadcasting in the United States had strong hierarchical and contagious components operating at the same time in the early years. If we plot the populations of American cities against their rank order (Figures 5a and b) and connect the values with a line, we can use the graph as a base for plotting the places that "adopted" radio broadcasting during a particular year.* Broadcasting started in Pittsburgh in

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*To include all of the cities, a break of scale occurs on the vertical axis, and a tally of cities less than 100,000 and below 130th in rank is kept in a score box.

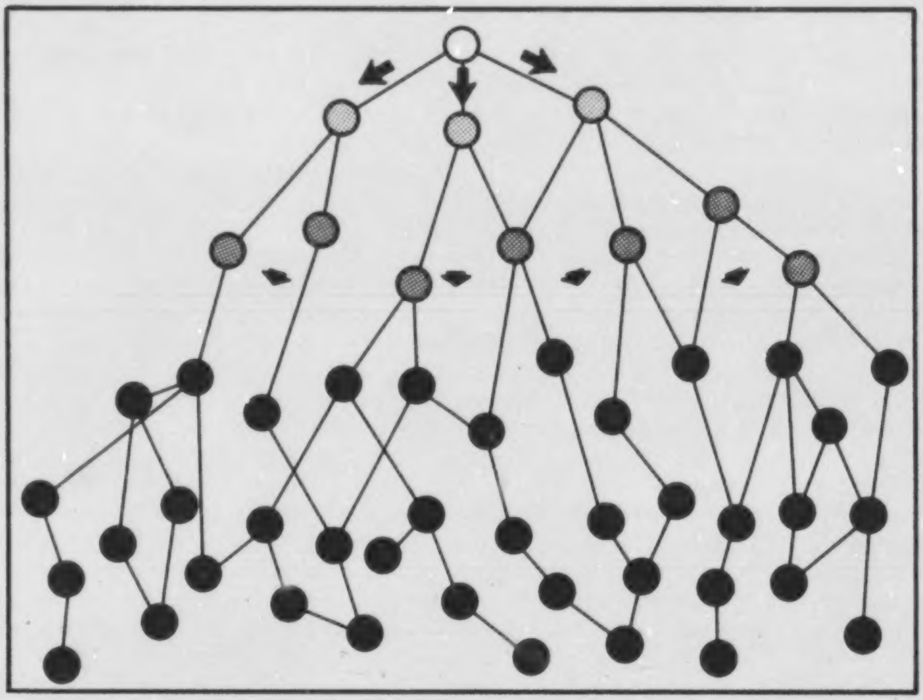
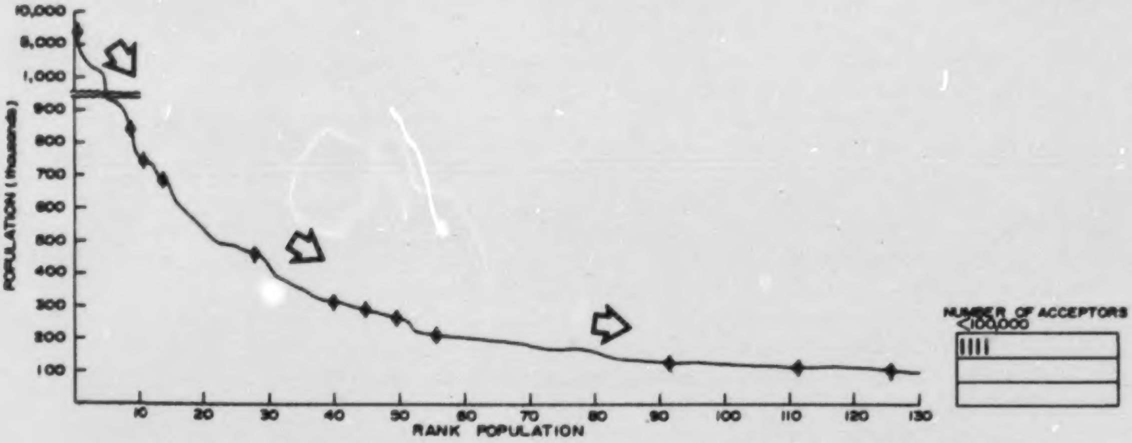


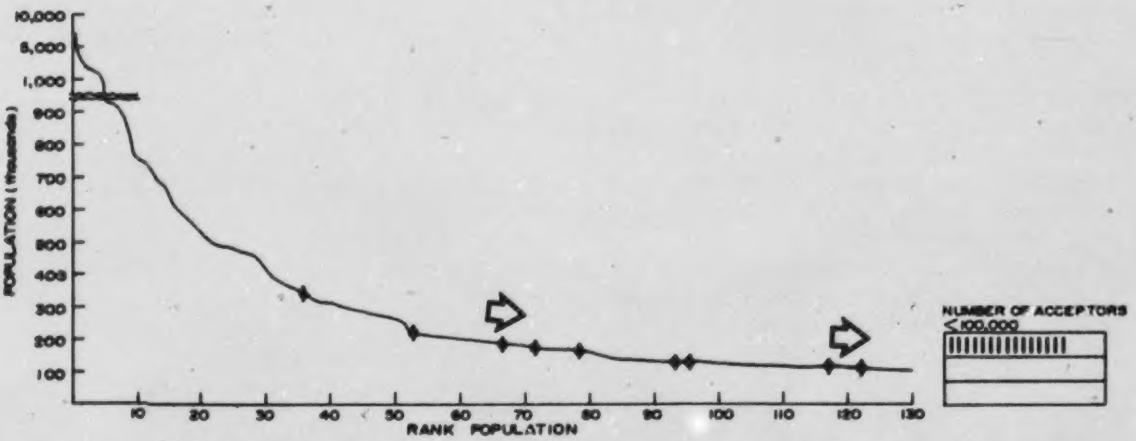
FIGURE 3. The Process of Hierarchical Diffusion

	Contagious	Hierarchical
Expansion	Ideas and innovations at local level; diseases; cooperative societies.	Ideas, innovations, fads through urban and central place structures.
Relocation	Migration waves; hollow frontiers.	Movements of scholars in universities; transfers of students; "stepping stone" migration.

FIGURE 4. A Cross-Classification of Some Types of Diffusion Processes



a. Accepting Cities High on the Rank-Size Graph, 1921



b. Accepting Cities Lower on the Rank-Size Graph, 1924

FIGURE 5. Adoption of Radio Broadcasting (adapted from Bell, 1965)

1919, and by 1921 only four places with less than 100,000 people had stations, though many of the larger cities possessed the modern innovation. However, by 1924 most of the new acceptances were in towns below 100,000, and all the cities over 360,000 had received radio broadcasting before this date.

While we can think of the innovation "sliding down" the rank-size graph as it trickles through the urban hierarchy, it is also clear that some contagious diffusion was occurring at the same time. In 1921 (Figure 6a), many of the large metropolitan places like New York, Boston, Detroit, St. Louis, San Francisco, Los Angeles, and Seattle had radio stations, together with some of the smaller cities such as Dallas, Des Moines, Kansas City, and Knoxville. By 1924 (Figure 6b), many of the towns around the innovating cities had "caught the radio bug," the contagious effect being particularly noticeable around Kansas City and Des Moines where nearby towns were caught between the early stations. Similarly, around San Francisco, Seattle, Detroit, Cleveland, and Philadelphia, the contagious explosion had started, with radio stations in a number of small towns far down the urban hierarchy but close to one of the early innovating centers. Thus, we have a diffusion process convoluting both hierarchical and contagious effects in which the former appears more important in the earliest years, while the latter assumes greater control once the basic patterns are established. We can think perhaps of innovating "stones" being dropped into the still millpond of America's space, each one producing a wave-like pulse of contagious innovation to cities in its area of influence.

Thinking of diffusion processes in terms of *waves* is a common verbal and conceptual analogy stemming from an early work entitled *The Propagation of Innovation Waves* by Torsten Hägerstrand, the great Swedish pioneer of modern geographic diffusion studies. One of his early studies in Sweden investigated the diffusion of automobile ownership which seemed to sweep like a wave across the province of Skåne. Based on an hexagonal network of observation cells (Figure 7a), he recorded the growth of automobile ownership, noting that Skåne often gets innovations from the rest of Europe before other parts of the country. In 1920 (Figure 7b), car ownership was scattered in a few towns, but two years later (Figure 7c), the "wave of innovation" had washed strongly across the area from Denmark and its capital city of Copenhagen. By 1924 (Figure 7d), the new horseless carriage had penetrated nearly every corner of the province.

The wave analogy, like all analogies, must be used with care and circumspection. It is a useful conceptual device for thinking about certain types of diffusion processes provided it is not taken too literally in all cases. For some types of diffusion the wave stands as a useful model of the actual diffusion process.

A *model* is an abstraction, simplification, and compression of reality, constructed to illuminate something complex that is intellectually intriguing. In this sense, a map is a model, for it selects from the overwhelming complexity of the real world a few important things, and indicates in a convenient "modeled space" their spatial juxtapositions. The act of "mapping" is not simply a geographical one, but a conceptual one in which many things are compressed and simplified to a few – sometimes by rigorous and well-specified mathematical rules. Models are filters through which we look at the real world. If they are good filters, they increase our understanding by letting us see pattern and order in what formerly seemed chaos. Thus, the wave is a simplification – a model – of a diffusion process, and it seems to stand up well when the process involves individual decisions to adopt an innovation.

Like all waves, innovation pulses across a landscape tend to lose their strength with distance from the source of the disturbance. If we plot for a number of time periods the proportion of people accepting a new idea against their distance from the source (Figure 8), we can see how an innovation wave gradually fades away. During the first

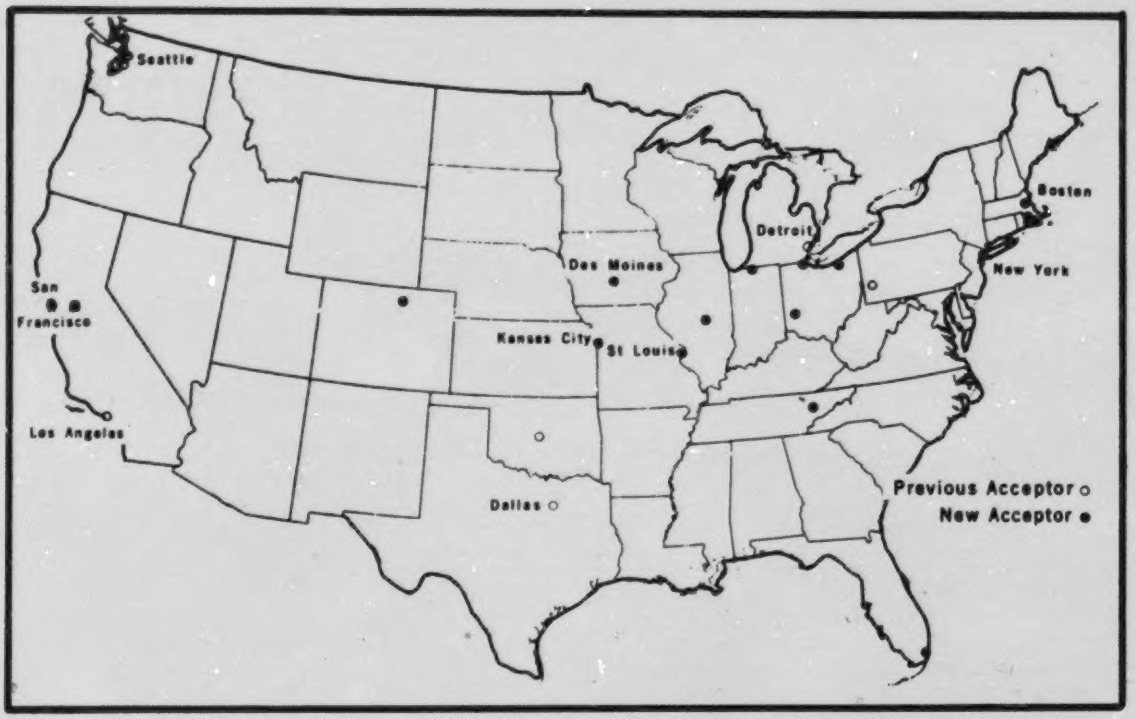

Seattle
San Francisco
Des Moines
Detroit
Boston
New York
Kansas City
St Louis
Los Angeles
Dallas
Previous Acceptor ○
New Acceptor ●

FIGURE 6a. Cities Adopting Radio Broadcasting in 1921 (adapted from Bell, 1965)

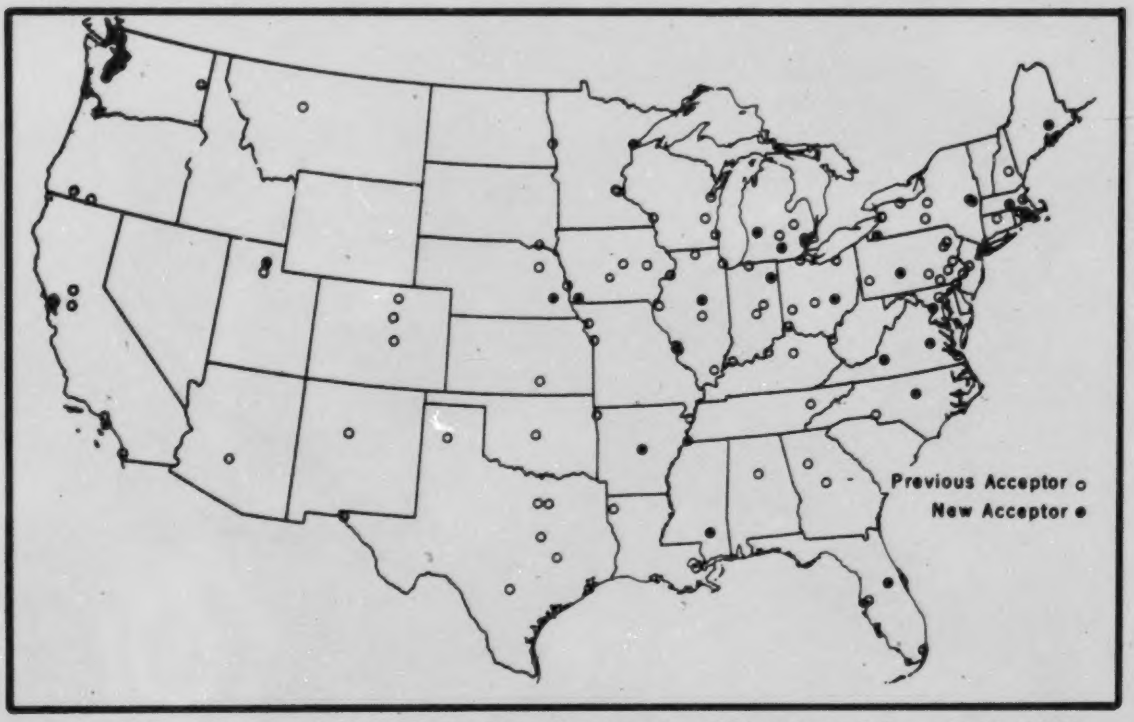

Previous Acceptor ○
New Acceptor ●

FIGURE 6b. Cities Adopting Radio Broadcasting in 1924 (adapted from Bell, 1965)

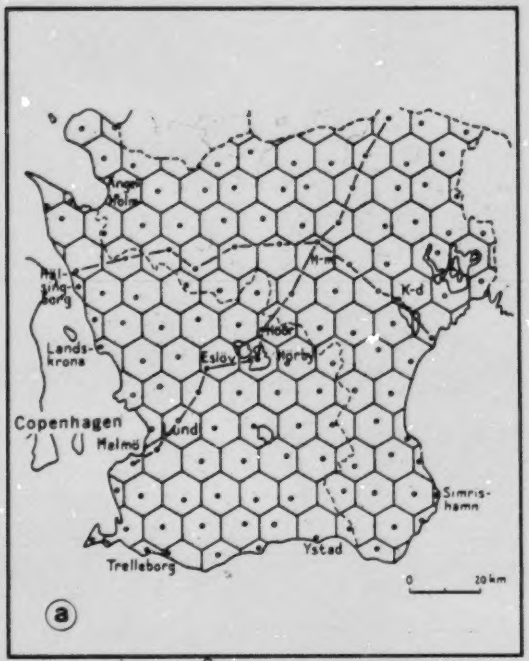
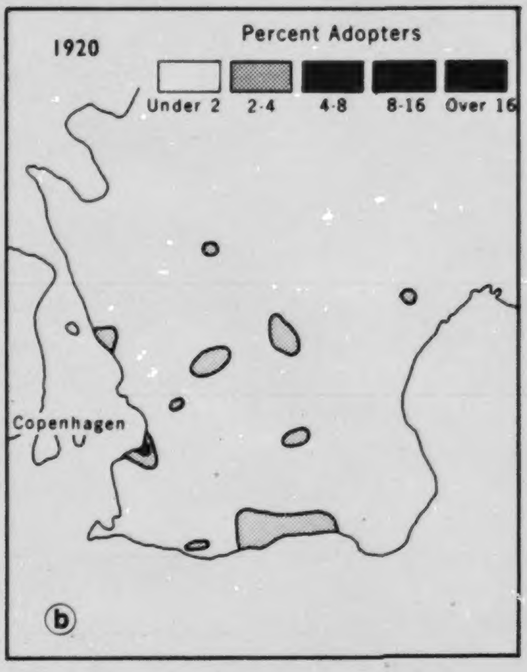
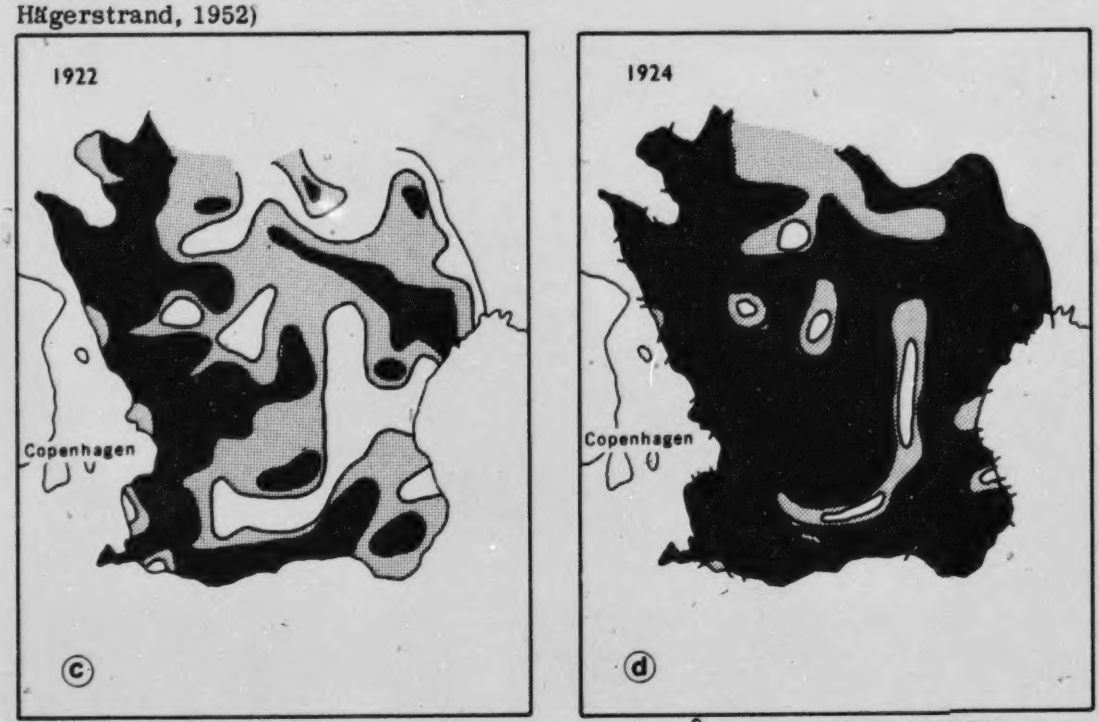

Angel-holm
Häl-sing-borg
Lands-krona
Copenhagen
Malmö
Lund
Eslöv
Höör
Hörby
H-m
K-d
Simris-hamn
Ystad
Trelleborg
0
20km
a

FIGURE 7a. Skåne, Southern Sweden: the network of observational cells (from Hägerstrand, 1952)


1920
Percent Adopters
Under 2
2-4
4-8
8-16
Over 16
Copenhagen
b


1922
Copenhagen
c
1924
Copenhagen
d

FIGURES 7b-d. Adoption of automobiles in Skåne, 1920, 1922 and 1924 (adapted from Hägerstrand, 1952)

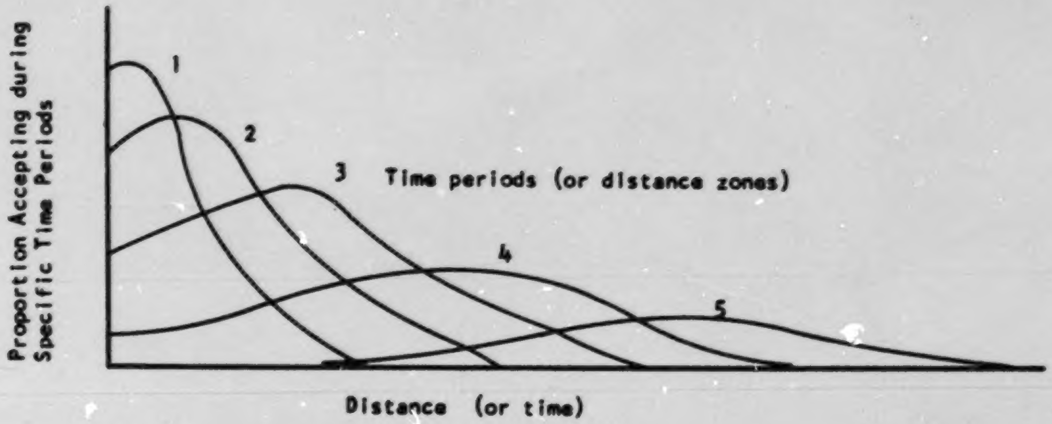


FIGURE 8. Waves of innovation losing strength with distance from the source area (from Morrill, 1968)

time period, many people close to the origin accept the innovation, while only a few further away make the decision to adopt. In the second time period or "generation," the wave has moved outward, but the crest is lower and the energy of the innovative pulse is spread over a wider area. During successive periods the crest continues to move away from the source area, but with ever-diminishing intensity, until the wave has completely spent its force. The same sequence also characterizes many pioneer settlement waves. Land is taken up rapidly close to the origin of the migration in the early time periods, but later the crest of the pioneer wave moves outward, and during the final periods the "acceptances" near the origin have declined greatly, representing simply a filling-in of the area.

. . . and the Barriers

Diffusion processes are influenced not only by the basic characteristics we have considered so far. Usually they do not move over smooth and homogeneous surfaces, for real geographic space is seldom close to the theoretically ideal "transportation surface," where movement is equally easy in all directions. Many things get in the way, slow down, and alter the course of other things that are diffusing through an area. The unfolding patterns of innovation, migration, and urban growth that we see in sequences of maps are never even and symmetrical, like a circular wine stain expanding on a tablecloth. Rather they are channeled more quickly in some directions than others as barriers to diffusion slow down and warp the pure forms more familiar perhaps to the physical, rather than the social, scientist.

Barriers in the way of a diffusion wave can have three basic effects. Upon hitting an absorbing barrier, a pulse of innovation is stopped cold. We can think of all the energy of the process in the vicinity of such a barrier being completely absorbed so that the process of diffusion is halted. Impenetrable swamps and unscalable mountains, for example, can stop the diffusion of migration waves, and settlement waves tend to flow around such barriers if they can. In the same way, ocean waves tend to be refracted around islands that stand as absolute barriers (Figure 9). Considerable mixing and turbulence often occur on the leeward side of such barriers as two segments of a

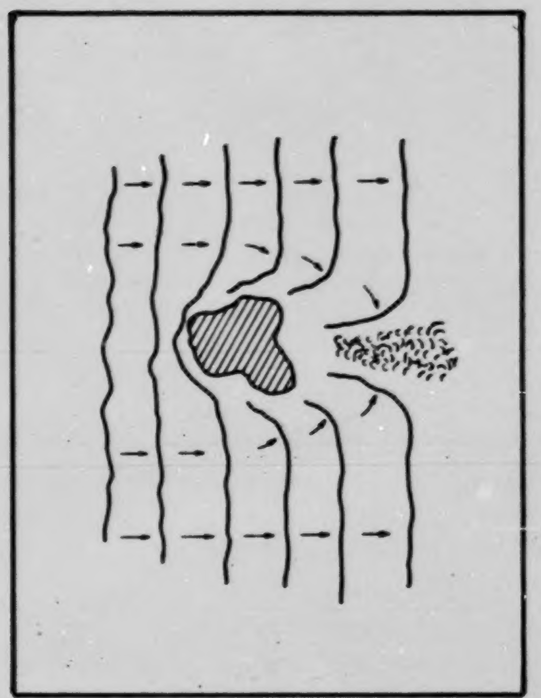


FIGURE 9. Ocean waves meeting an absolute island barrier (from Nystuen, 1967)

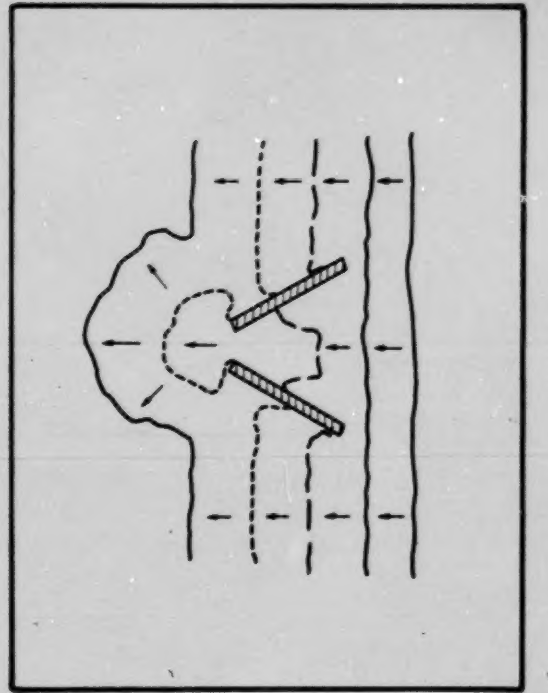


FIGURE 10. Waves meeting two reflecting barriers (from Nystuen, 1967)

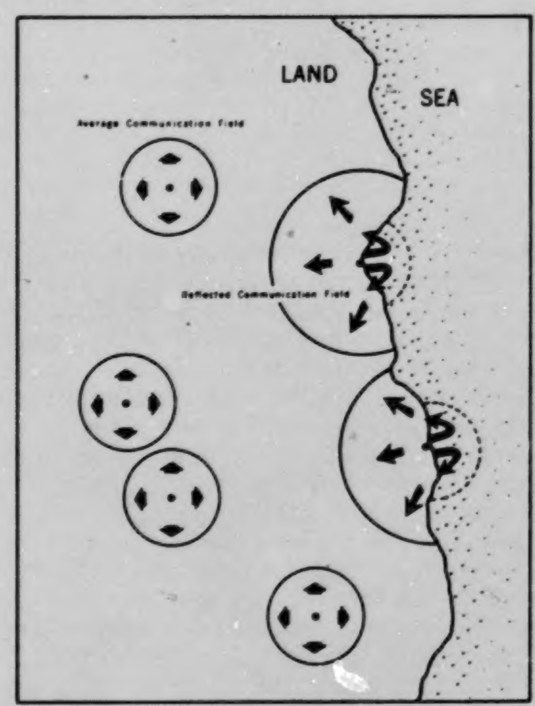

LAND
SEA
Average Communication Field
Reflected Communication Field

FIGURE 11. Personal communication fields reflected by seacoasts

wave clash before it forms again and goes on its way. In the South Pacific, such lines of turbulence are often phosphorescent at night and are used by canoe captains to guide them home.

Sometimes an innovation wave will hit a barrier and then bounce off it. Such barriers are termed reflecting, and they can often channel the energy of a diffusion process and intensify it in a local area. For example, a wave train approaching two reflecting barriers (Figure 10) will be slowed down initially as part of the energy is reflected inward. But, like a weir in a river, the build-up of energy will eventually be released explosively so that the wave front is pushed out and distorted. We can speculate that seacoasts may form reflecting barriers for flows of communication generated by people who live on the land-water boundary (Figure 11). If we assume that there is a certain communication field around the average person that fulfills his personal need for normal interaction with others, then a person living on the coast has half of his field cut off – unless he wants to talk to the fishes! We really do not know, but it is possible that he will compensate for this excision of his field by expanding its radius on the landward side. In a sense, his need for an average amount of communication bounces off the reflecting seacoast barrier and extends his communication field further inland.

Sometimes a barrier may play both absorbing and reflecting roles, depending upon the mechanism of the diffusion process. Suppose, for example, a forest of maple trees is extending north into a new area bordered on the west by a lake (Figure 12). Its seeds are windblown, and near the lake some of these will fall in and be lost – or absorbed by the barrier. The reproductive energy of a forest will be reduced locally, and the boundary might lag behind the rest of the advancing front. On the other hand, the lake will have a quite different effect upon an advancing forest of walnut trees, whose nuts are carried and buried in the ground by squirrels (Figure 13). If the squirrels near the lake work just as hard as those further away, they will tend to be reflected by the lake so that the western edge of the walnut forest will advance ahead of the rest. This illustration, though very simple and even fanciful, makes an important point. Barriers must be functionally defined: when we talk about them, we must also consider the type of diffusion process with which they interact.

Pure absorbing and reflecting barriers are rare. In most cases, barriers are not absolute but are permeable, allowing part of the energy of a diffusion pulse to go through, but generally slowing down the intensity of the process in the local area (Figure 14). A long, narrow lake, for example, may not completely stop communication between people who live on opposite sides (Figure 15), but the intensity of western communication flow (daily telephone gossip, for example) will be much less than with people to the east. Similarly, a political boundary can seldom be completely sealed; and, although it may absorb much of the energy of potential interaction across it, a trickle always gets through. Suppose we consider the telephone traffic of Gossipville with other towns in the region (Figure 17a), and plot on a graph the number of calls the town generates against the distance they are away (Figure 16). As distance increases, the intensity of the interaction declines. Now suppose a political boundary is placed through the area (Figure 17b). It is permeable, so rather than cutting telephone traffic completely it simply reduces it (Figure 16). How can we measure the barrier effect? One way is to try to line up the two pieces of the graph by displacing the lower segment to the right. The amount we have to displace the segment now becomes our measure of the barrier effect in terms of distance units. In this way, we could say that a particular permeable barrier has the equivalent power to reduce communication as a certain distance. Diffusion through the region will also be retarded. Even where a political boundary is very permeable, as between the United States and Canada, there is always some barrier effect. In Europe, political boundaries often mark changes in language

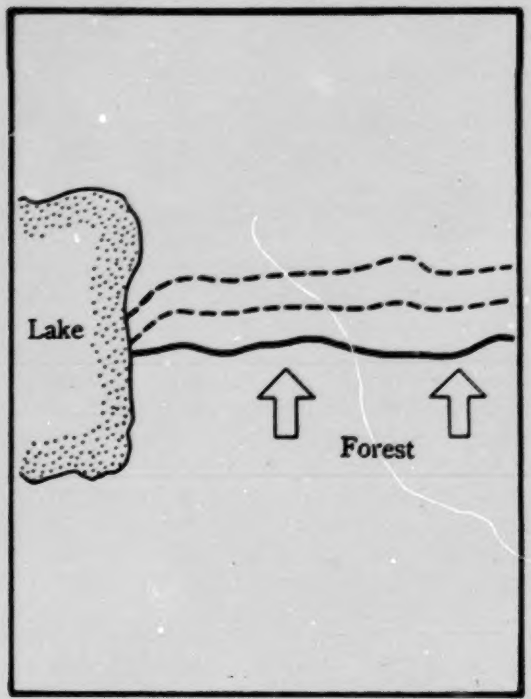

Lake
Forest

FIGURE 12. An advancing maple forest by an absorbing lake (from Nystuen, 1967)

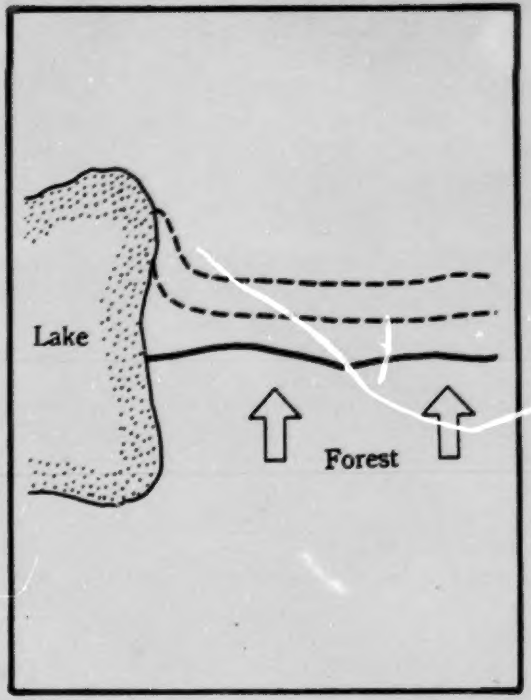

Lake
Forest

FIGURE 13. An advancing walnut forest by a reflecting lake (from Nystuen, 1967)

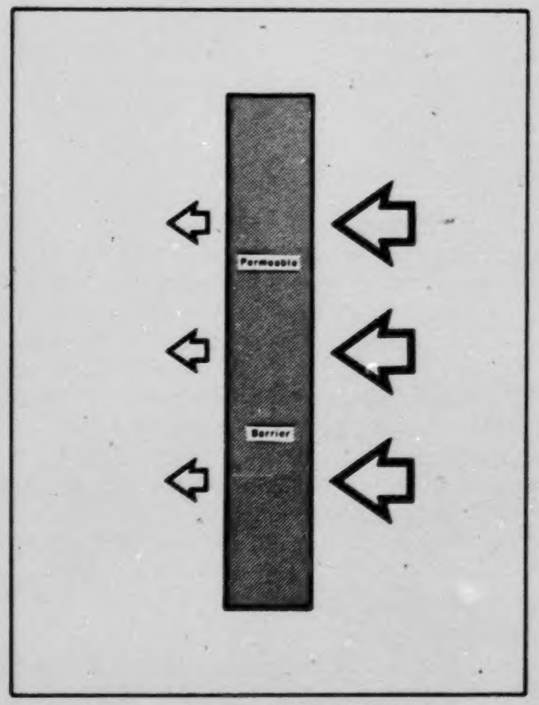

Permeable
Barrier

FIGURE 14. A permeable barrier reducing the flow through it (after Nystuen, 1967)

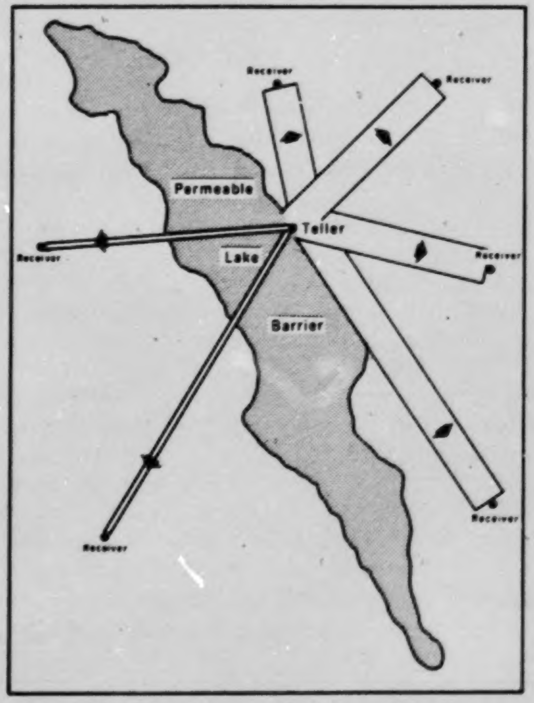

Receiver
Receiver
Permeable
Teller
Receiver
Lake
Receiver
Barrier
Receiver
Receiver

FIGURE 15. Communication flows reduced by a permeable lake barrier

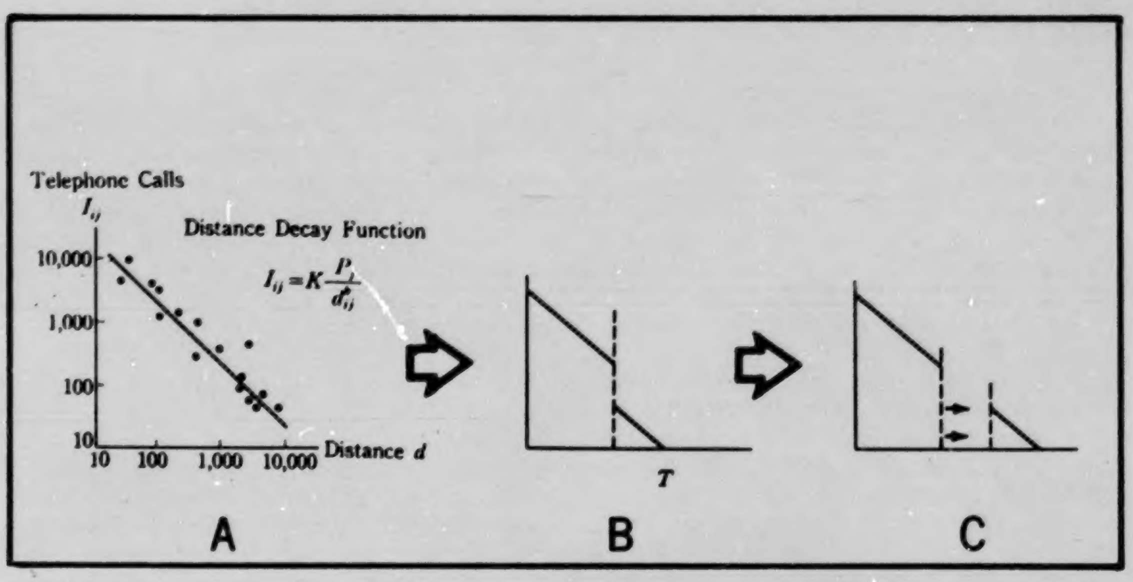


FIGURE 16. Measuring the effect of a political boundary upon flows of telephone calls (adapted from Nystuen, 1967)

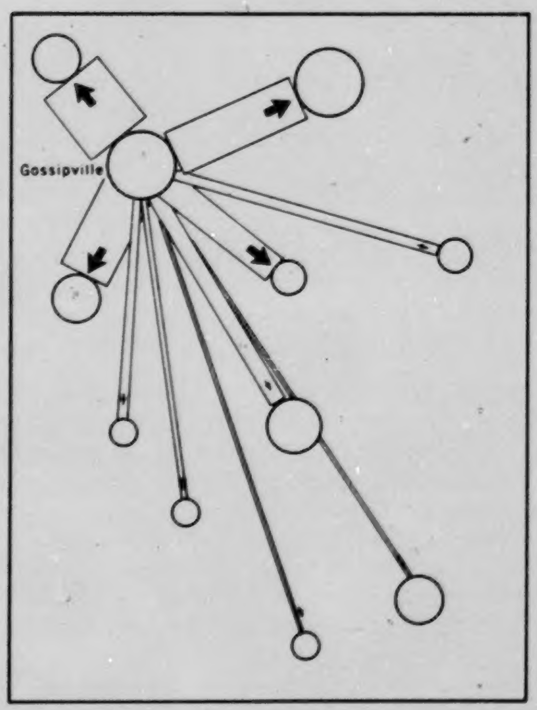

Gossipville

FIGURE 17a. Communication flows from Gossipville before hinterland severance

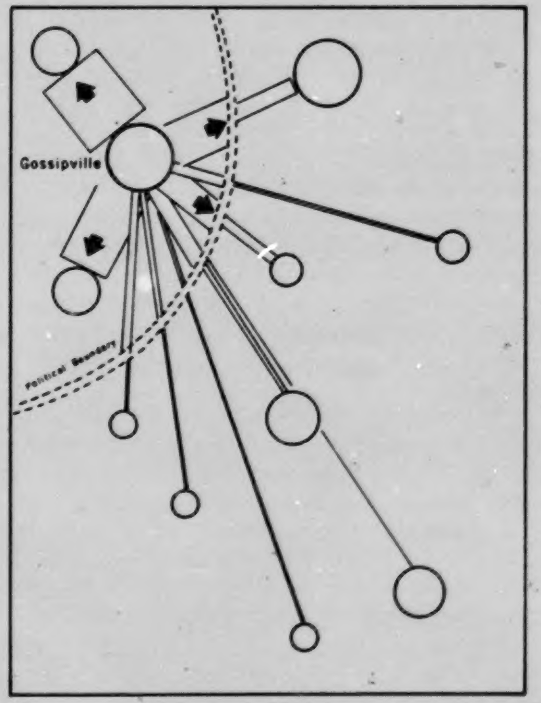

Gossipville
Political Boundary

FIGURE 17b. Communication flows from Gossipville after placement of political boundary

also, so the barrier effects are much stronger, slowing down communication and diffusion processes much more.

Rivers are often permeable barriers to the diffusion of urbanized areas moving in a contagious fashion from the original core of settlement. Few cities start on both banks of a river, and the side that receives the first settlement always seems to have an advantage (Figure 18). Many riverine cities in North America display the "truncated circle" effect as the process of urban diffusion is much more rapid on the side that got the initial head start (Figure 19). Typical of many such cities is Winnipeg, which started as a small pioneer settlement on the banks of the Red River in the middle of the 19th century (Figure 20). By 1880, the urban area had expanded considerably on the side of the founding settlement, but the opposite bank had only received a small dab of urbanization. The original advantage is held even today as the city has exploded on one side but has developed much more slowly on the other, as the river has formed a permeable barrier to the diffusion of urbanization.

While we have considered the general properties that barriers may possess in fairly abstract ways, in reality they come in many different varieties. The most obvious, perhaps, are the physical barriers—the mountains, deserts, swamps, lakes, and oceans. At one time they may have been totally absorbing, but today their permeability is increasing rapidly, and for some types of travel and communication they no longer exist. In earlier days, however, when the technology of transportation and communication was at a much lower level, physical barriers were often important, slowing down the rates at which ideas, innovations, and people could diffuse over the land. In the eastern United States, for example (Figure 21), the Appalachians slowed down severely the rates of travel from New York City in 1800. While five days coaching could get one traveler far along the Hudson-Mohawk corridor, another moving west would be slowed down by the succession of ridges and valleys in Central Pennsylvania. Even within this folded mountain area, the long narrow valleys formed by high, parallel ridges influenced patterns of communication and human interaction (Figure 22). Marriage ties within the same valley, for example, seem to have been much more probable than across the ridges of low permeability to other valleys, and today distinctive groups of family names lie along the same alignments. Even adoptions of farming equipment are shaped today by the distorted information fields, and innovations like hay driers diffuse much more quickly along the narrow valleys than "across the grain" of the land.

Barriers to diffusion processes may be far more subtle than the physical ones that are so easily seen upon the landscape. Often they are cultural in nature and take many different forms. Where ideas spread by telling, differences in language can greatly retard their diffusion. The intensity of telephone traffic generated by Montreal, for example, depends not only upon the size and distance of the receiving centers but whether the towns are in Quebec or Ontario. The linguistic barrier at the boundary of the French and English parts of Canada is very marked, and the political consequences have always been felt in Canadian history. Europe is also wracked by linguistic barriers, and new ideas, whether cultural or technological, diffuse far less quickly than in the United States. Servan Schreiber in The American Challenge comments upon the distressing political consequences of such barriers, noting that only the United States seems capable of taking advantage of the Common Market, for the thinking of Americans simply overrides such barrier problems.

Linguistic barriers are some of the most stable and long lasting in their effects, although a language may itself diffuse slowly through an area. English has diffused during the past century to many parts of the world, and appears today as the major language for most commercial and technical discussions. But language diffusion may take many generations. Along the boundary of Sweden and Finland, for example, the

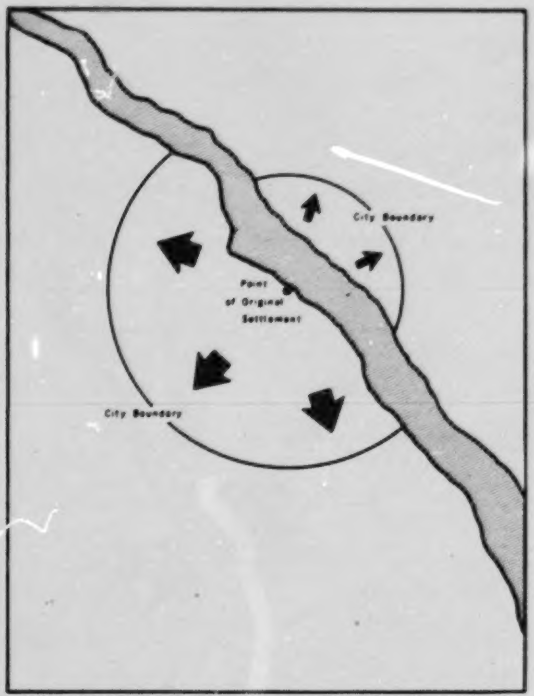

City Boundary
Point
of Original
Settlement
City Boundary

FIGURE 18. Effect of permeable river barrier upon the diffusion of a city

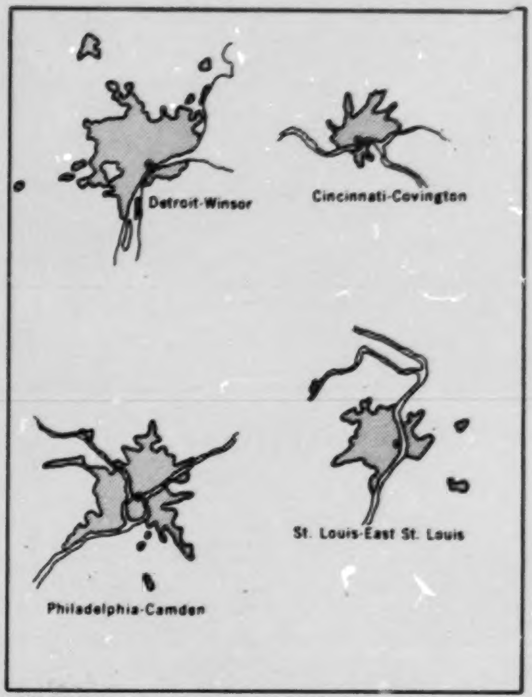

Detroit-Winsor
Cincinnati-Covington
Philadelphia-Camden
St. Louis-East St. Louis

FIGURE 19. Barrier effects of rivers upon some North American cities

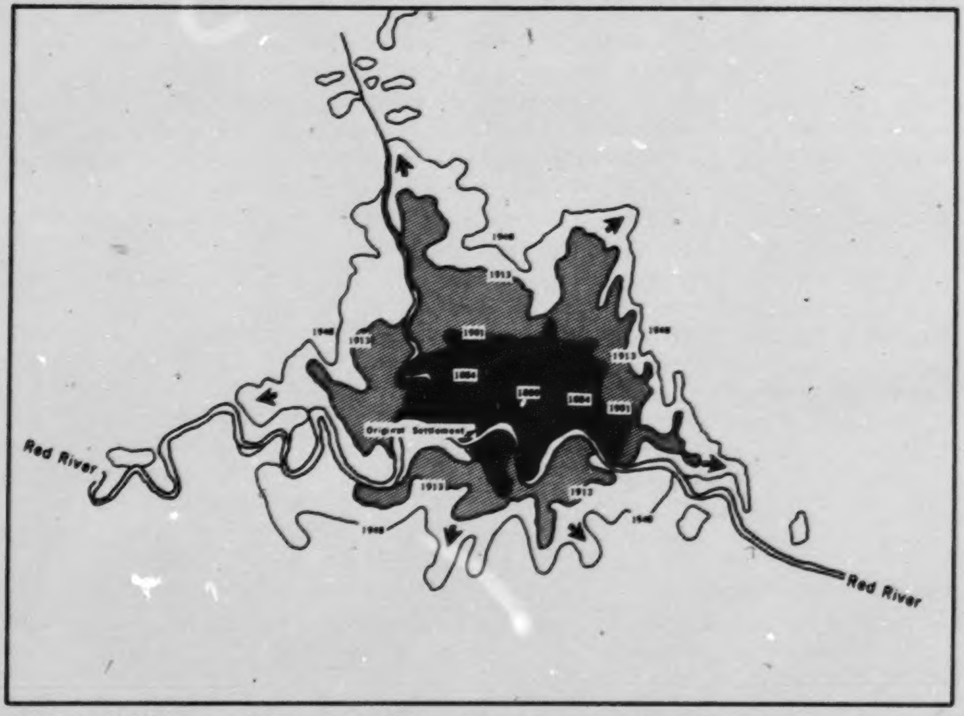

1948
1913
1948
1913
1901
1948
1913
1884
1880
1884
1901
Original Settlement
Red River
1913
1913
1948
1948
Red River

FIGURE 20. Diffusion of Winnipeg from site of original settlement on the Red River

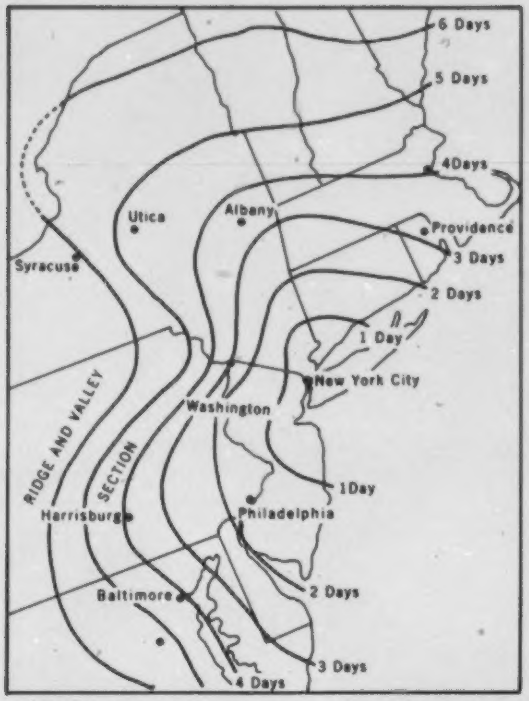

6 Days
5 Days
4Days
Utica
Albany
Providence
Syracuse
3 Days
2 Days
1 Day
New York City
Washington
RIDGE AND VALLEY
SECTION
1Day
Harrisburg
Philadelphia
2 Days
Baltimore
3 Days
4 Days

FIGURE 21. Travel times by stagecoach from New York in 1800 (after Brown, 1948)

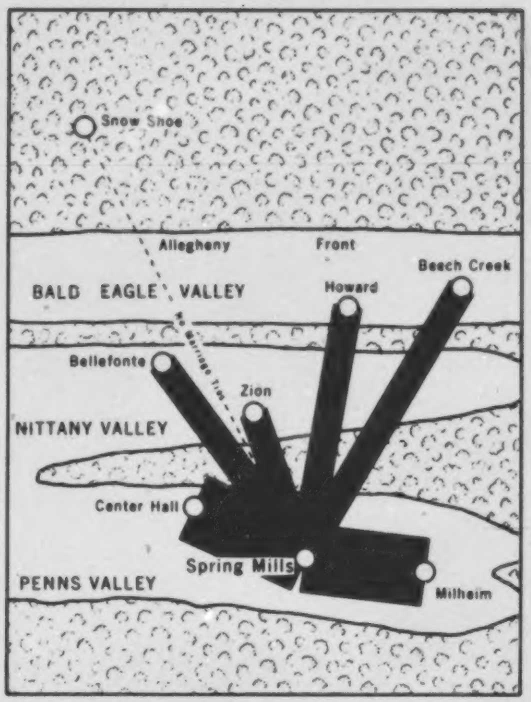

Snow Shoe
Allegheny
Front
Beech Creek
BALD EAGLE VALLEY
Howard
Bellefonte
marriage ties
Zion
NITTANY VALLEY
Center Hall
Spring Mills
PENNS VALLEY
Milheim

FIGURE 22. Intensity of marriage ties in ridge and valley section of Pennsylvania

Finnish language seems to be gradually creeping in. Finland subsidizes its northern pioneer agriculturalists, while Sweden does not. A preponderance of young, and presumably lonely, males on the Swedish side and a more even balance between the sexes on the Finnish side means that many young Swedish men near the border marry Finnish girls. The first language of the children, however, is that of the mother, and Finnish appears to be slowly diffusing southward into ostensibly Swedish families.

Religious and political barriers may also thwart or slow down the diffusion of innovations. A number of international organizations of a fraternal nature are forbidden in some countries on political grounds, and Rotary International has yet to diffuse to the countries of Europe with totalitarian regimes. Other innovations, like physical and chemical methods of birth control (hopefully absolute barriers to a diffusion process themselves), have their rates of acceptance slowed down by religious barriers. Some of the great religious controversies of contemporary times involve the permeability and ultimate removal of such cultural barriers. Thus, in some cases, the effects of barriers change under pressure from the process of diffusion itself.

Where a course of diffusion is dependent upon human beings making individual decisions to adopt or reject, it is clear that the major barriers to the process may lie in the minds of men. In many cases, therefore, we are dealing with psychological barriers which can speed up or retard the course of an innovation. These barriers sometimes appear to be either completely absorbing or completely permeable; but, when many adoption decisions are examined, psychological barrier effects appear more complicated. In any area through which a new idea may diffuse there will always be some early innovators who adopt first (Figure 23). Once they set the example, however, they are quickly followed by a group called the early majority, and their example brings in the late majority in turn. Finally come the laggards at the tail end when nearly everyone else has adopted the new practice.

The symmetrical, bell-shaped, or normal curve describing the distribution of innovators and laggards may be expressed in a somewhat different way. Let us construct a graph with the proportion of people adopting an innovation along the vertical axis, and the time of adoption along the horizontal axis (Figure 24). We can start on the left and gradually accumulate the proportion of adopters as we move to the right. When T is small, at the start of the diffusion, we shall only accumulate a very small proportion of early innovators. As T increases, however, the proportion of adopters rises quickly as the early majority come in. At this point, a further move to the right of the normal curve brings in the late majority, but the diffusion is obviously slowing down as the cumulative curve on the graph begins to turn the other way. Eventually the laggards come in, and the diffusion wave is over.

The S-shaped curve describing the course of a diffusion process is known as a logistic curve. It is a very common one in diffusion problems, and there are good theoretical and empirical reasons why such a curve describes many processes of diffusion in which some people who already have adopted an idea tell others about it. The curve is described by the equation:

$$P = \frac{U}{1 + e^{(a-b.T)}}$$

which is not as formidable as it appears if we take it apart and interpret the various pieces (Figure 25). The equation actually links P (the proportion of adopters) to T

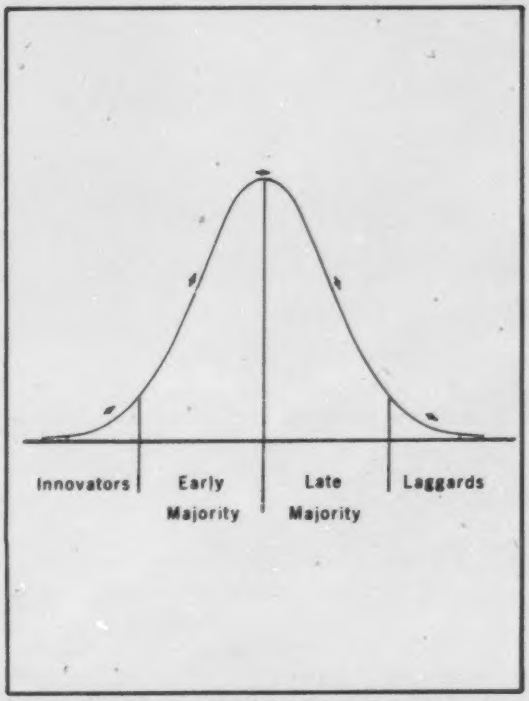


FIGURE 23. Distribution of innovation acceptors

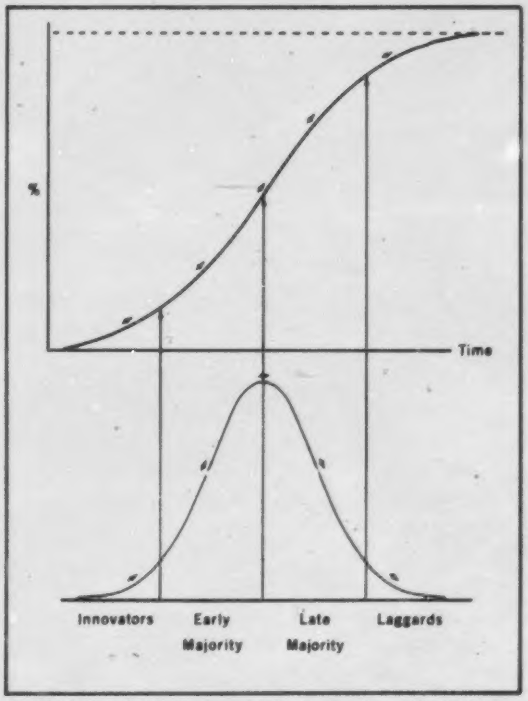


FIGURE 24. Accumulating the distribution of innovation acceptors

(the time at some point in the diffusion process). The numerator U is the upper limit, and we may substitute 100 if we want to represent the upper adoption limit at 100 percent of the potential adopters. On the other hand, not all the people in the area may be potential adopters of an innovation, and U may be less than the level of complete saturation. The lower-case letter e is a mathematical constant (like π), with the approximate value of 2.7183. This constant is raised to the power or exponent (a - b.T), where a and b are particular values that will change from one diffusion problem to another. The value of (a) controls the height above the T axis where the S-shaped curve starts, while (b) determines how quickly it rises. Since they fix and define a particular curve, so that it cannot be confused with any others, they are known as parameters.*

To see how different values of (a) and (b) change the S-shaped diffusion curve, let us set U to 100, (a) to 3.0, and (b) to 1.0 (Figure 26). Our expression becomes:

$$P = \frac{100}{1 + e^{(3.0 - 1.0T)}}$$

Notice that when T is zero, P becomes approximately 100/21 or roughly 5.0, implying that at the beginning of this particular innovation process about 5 percent of the early

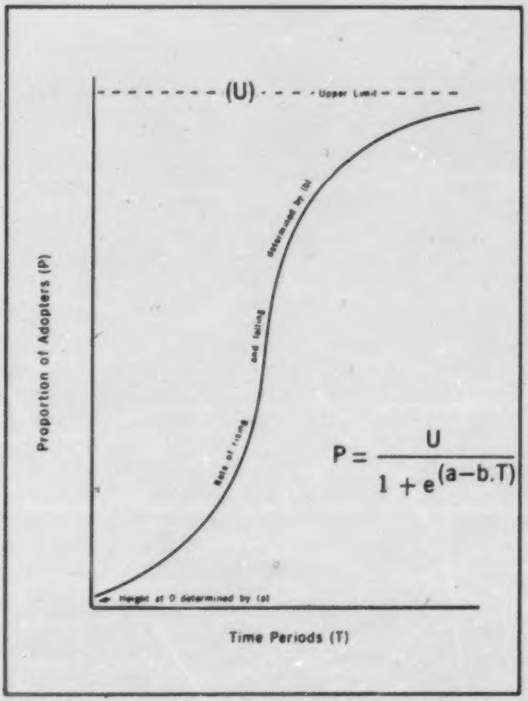


FIGURE 25. The logistic curve of innovation adoption

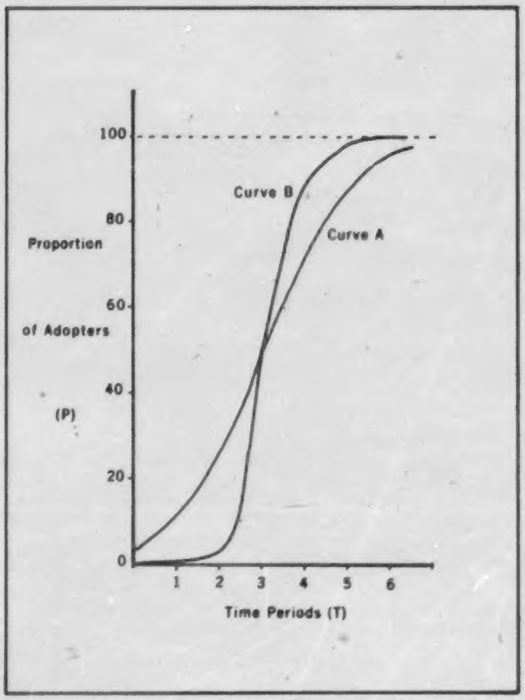


FIGURE 26. Curves of innovation adoption controlled by different parameters

innovators have adopted the new idea (Curve A). As time passes, and T gets bigger (measured in whatever units we think are appropriate—weeks, months, or years), the exponent (a - b.T) becomes smaller and smaller. For example, when T is 3.0 the exponent is zero. Like any other number, the constant e raised to the zero power is 1.0, so P is now 100/2 or 50 percent. This implies that by the third time period the diffusion process is halfway through, and all the innovators and early majority have accepted. The curve has moved slowly upwards, and hereafter it will begin to turn the other way as the late majority and laggards come in. Gradually it gets closer and closer to the upper limit U, or 100 percent.

---

*Parameter is probably the most misused word in the whole scientific vocabulary. Parameters are constants in a relational expression that determine how two or more variables change together. Do not make the mistake of using the word to describe the variables themselves.

To see how the values of the parameters (a) and (b) control the shape of the S-curve, let us set (a) to 12.0 and (b) to 4.0. Our expression becomes:

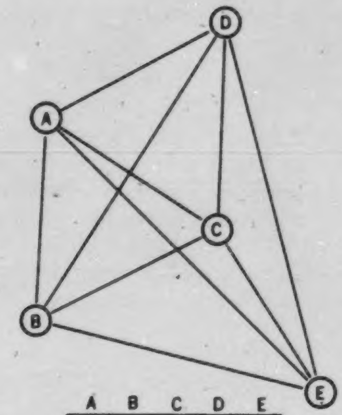
$$P = \frac{100}{1 + e^{(12.0 - 4.0T)}}$$

Now when T is zero at the beginning of the diffusion process, the constant e is raised to the 12th power! Obviously the denominator is a very large number, so $\overline{P}$, the proportion of very early innovators, is very small (Curve B). As time passes and T gets bigger and bigger, the exponent (12 - 4.T) gets smaller and smaller. But notice how the proportion of adopters remains small until T is about 2.0 or 2.5. Suddenly the innovation takes hold, the innovators adopt, and their behavior is quickly imitated by the early majority. These, in turn, are copied by the late majority, and by the fourth time period even most of the laggards have come in. The curve soars upwards as the innovation wave finally breaks out of the source area, bursts across the landscape, and finally crashes upon the most remote parts of the region!

We can summarize all these barrier effects by considering a very small spatial system of five nodes (Figure 27), in which things may diffuse along the lines of communication that join each node directly to all the others. We can draw up a five-by-five table or matrix containing the proportion of times, or probabilities, that one node will communicate with others in the system. The nodes may be people, towns, or even census districts or countries—the same principles hold. If the nodes are of equal size, and distance has no retarding effect upon communication, then we would expect each node to communicate with all the others in roughly equal proportions. Notice that the rows always sum to 1.0, for we assume a closed system here, a set of people or villages cut off from the rest of society or urban system.

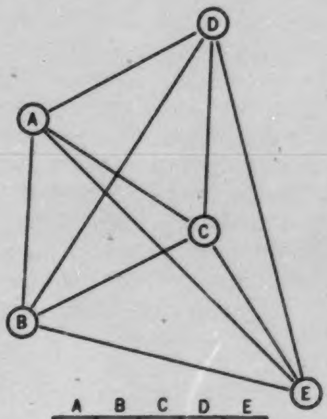
If distance has an effect upon communication (Figure 28), we would expect new ideas and messages to move with greater probability between nodes close together, compared to those farther apart. We can describe such frictional effects upon message flows by simply changing the values of the probabilities of interaction between a pair (a row and a column) in the matrix. Town A, for example, is roughly equidistant from B, C, and D and has roughly the same chance of passing a message to them at any one time ($p = 0.15$). Town E is farther away, and its chance of getting a message from A is much smaller ($p = 0.05$). If the nodes are of different sizes, then a big center like D will generate and receive more messages than its smaller neighbors (Figure 29). In the interaction matrix, the probabilities of generating and receiving change accordingly, and D's column has very large values compared to the others.

Finally, we can introduce our three sorts of barriers (Figure 30). Town B is behind an absolute, absorbing barrier, and as it is severed from the system its row and column in the matrix both contain zeros. Town A cannot communicate directly to D, but it can send its messages to C which reflects them to D (equivalent to English and German families communicating during the Second World War via the Red Cross



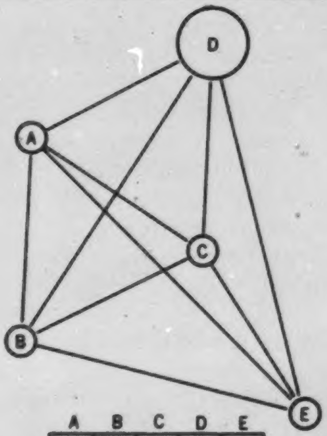
	A	B	C	D	E
Town A	.20	.20	.20	.20	.20
Town B	.20	.20	.20	.20	.20
Town C	.20	.20	.20	.20	.20
Town D	.20	.20	.20	.20	.20
Town E	.20	.20	.20	.20	.20

FIGURE 27. Communication matrix for equal nodes and no distance effects



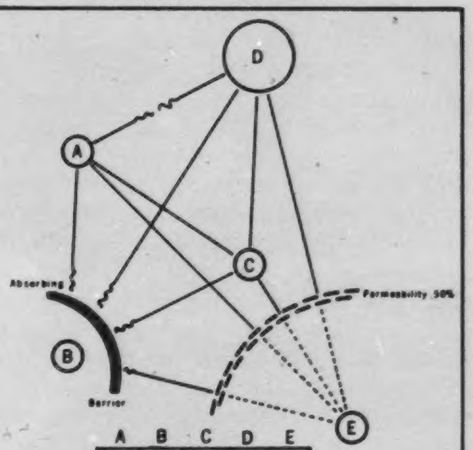
	A	B	C	D	E
Town A	.50	.15	.15	.15	.05
Town B	.18	.50	.18	.06	.08
Town C	.12	.12	.50	.11	.15
Town D	.19	.06	.19	.50	.06
Town E	.07	.12	.24	.07	.50

FIGURE 28. Matrix for equal nodes with frictional effects of distance



	A	B	C	D	E
Town A	.50	.07	.07	.34	.02
Town B	.12	.50	.12	.20	.06
Town C	.06	.06	.50	.30	.08
Town D	.19	.06	.19	.50	.05
Town E	.05	.08	.15	.22	.50

FIGURE 29. Matrix for unequal nodes and effects of distance present



	A	B	C	D	E
Town A	.50	0	.49	0	.01
Town B	0	1.0	0	0	0
Town C	.07	0	.34	.56	.03
Town D	0	0	.48	.50	.02
Town E	.07	0	.17	.26	.50

FIGURE 30. Matrix for system with permeable and absorbing barriers

in Switzerland). Thus the proportion of messages between A-D are added to those normally going between A-C and C-D and raise the values in the matrix accordingly. Town E is on the other side of a permeable barrier which cuts the chance of a message down by one-half, reflected in the matrix by very small values in E's row and column. Thus, the interaction or diffusion matrix summarizes most of our discussion. Contagious diffusion is likely where a population is fairly homogeneous and distance effects are strong. Hierarchical diffusion is more common when transmitting and receiving nodes are of greatly different sizes, and communication flows are more intense between the giants than between the small fry. Distance effects change the probabilities of interaction, and so warp and channel the diffusion of ideas as communication is cut down between distant places. Finally, absorbing, reflecting, and permeable barriers, which may be psychological, cultural, political, or physical, can all be expressed in terms of the elements of the interaction matrix. Absorbing barriers sever pieces from a system of spatial interaction, and turn rows and columns to zero; permeable barriers reduce some probabilities, and so twist and warp the "communication space" through which messages and ideas must diffuse.

III. Levels, Scales, and Cones of Resolution

Processes of spatial diffusion take place at many geographic scales. We should not be surprised, therefore, if we require many different models to help us clarify these difficult processes, which operate at a variety of levels. Shifts in scale are very common in all the sciences, and as men and women become dissatisfied with very general statements giving a very gross overview of a subject, they tend to direct their attention upon smaller and smaller pieces of the problem, shifting along a continuum from the macro- to the micro-viewpoint. The rise of many subjects with names prefixed by micro- attests to the shifts in scale that have taken place throughout science during the past half century. Stafford Beer, one of the great names in the field of operations research, has coined the provocative phrase "cones of resolution," implying that problems can be considered at many different levels and in varying degrees of detail (Figure 31). In any subject, the pendulum usually swings back and forth between the extremes, and with people working at all scales of inquiry, the "cones of resolution" are eventually filled with a hierarchy of models. More general models, high up in the cones, are supported by a number of others at lower levels.

Geographic diffusion processes may be considered in the same light (Figure 32). At the micro-scale on the lowest plane, ideas and innovations may spread through a

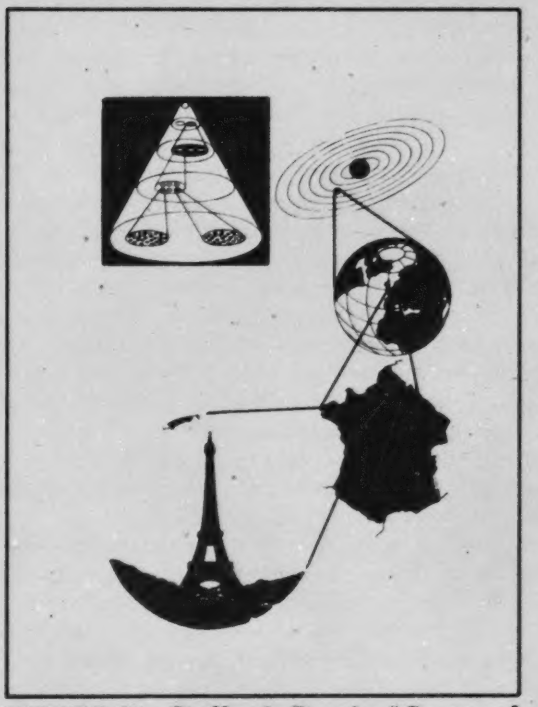


FIGURE 31. Stafford Beer's "Cones of Resolution" (from Beer, 1968)

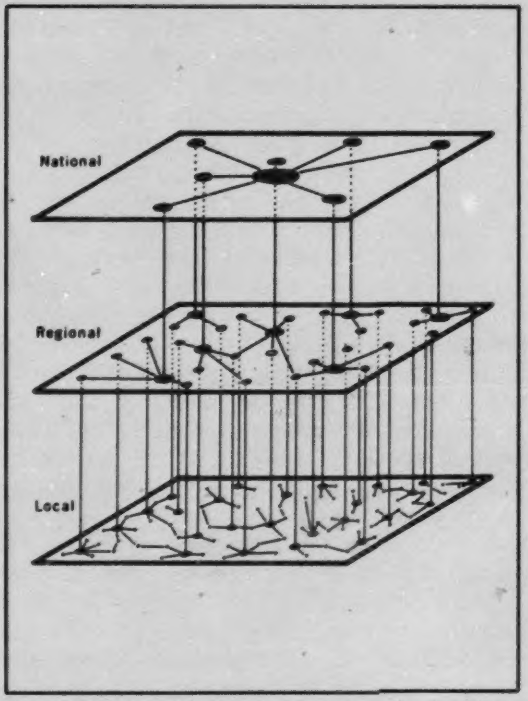


FIGURE 32. National, regional, and local planes of diffusion (adapted from Hägerstrand, 1953)

social communication network linking individuals to one another. But considered at the regional level, a different network of communication may come into play in the middle plane, probably closely aligned to the pattern of linkages between central places. Finally, on the upper plane, at the national or even international level, macro-flows of information, warped and shaped by great metropolitan fields, diplomatic relationships and ties, political consideration and so on, guide the course and intensity of diffusion processes. We shall consider each of these levels in turn, starting at the lowest plane where our models have the greatest degree of spatial resolution, and ending at the macro-level.

Diffusion at the Individual or Micro-Level

Many diffusion processes operate at the micro-level, where innovations and ideas diffuse from individual to individual. Small hand tractors for plowing and puddling padi spread from one Japanese rice farmer to another, often driving out more traditional methods of cultivation. As in Europe at an earlier time period, the horse in Japan disappears in a concomitant process of reverse diffusion. In the United States, tractors diffuse from a distinct pole of innovation in the flat wheatlands of North Dakota, while hybrid corn takes hold in Iowa to spread like a prairie fire through the Corn Belt. Membership in a progressive farmers club on Kilimanjaro, allowing Chagga coffee farmers to auction their high quality production at better prices, spreads across the face of the great mountain, channeled by the feeder roads and warped by the traditional hierarchical structure of chief and head man. From a family planning clinic in India, the loop diffuses from one woman to another as an innovation in birth control. In Colombia, new varieties of high-yielding beans diffuse from selected "seed villages." All these examples characterize diffusion processes involving individual, face-to-face communication before adoption takes place.

Most of the pioneer work on modeling diffusion processes comes from Sweden, where the spread of many innovations has been examined by Hägerstrand in considerable detail. For example, in the late 1920's the Swedish government tried to persuade farmers to abandon the old custom of allowing cattle to graze in the open woodlands during the summer months. The grazing cattle damaged the young growth, and a subsidy was offered to help the farmers fence and generally improve their pasture lands. In the early years (Figures 33a and b), distinct clusters of farms adopting the pasture improvement subsidy developed in the western part of the region, with one or two solitary innovators in the east. By 1931 (Figure 33c), the innovation had diffused rapidly in the west, moving out from the initial clusters of the earlier years. The eastern portion of the area seemed to lag behind, and only in the next two years (Figures 33d and e) did it begin to catch up while the pattern of adoption continued to thicken and develop in the west.

In examining such a sequence of maps, one is struck by the degree of spatial regularity in the unfolding pattern. It is almost as though a photographic plate were being developed and the "latent diffusion image" is there in the early maps waiting to appear after a certain lapse of development time. It was precisely from very careful examination of such map sequences that the first models of spatial diffusion were developed. We shall consider in some detail one that has become a classic, for not only does it give us great insight into a very complex spatial process but you may use it yourself as a base from which to make up examples of your own to get a "feel" for the way in which a spatially dynamic model works.

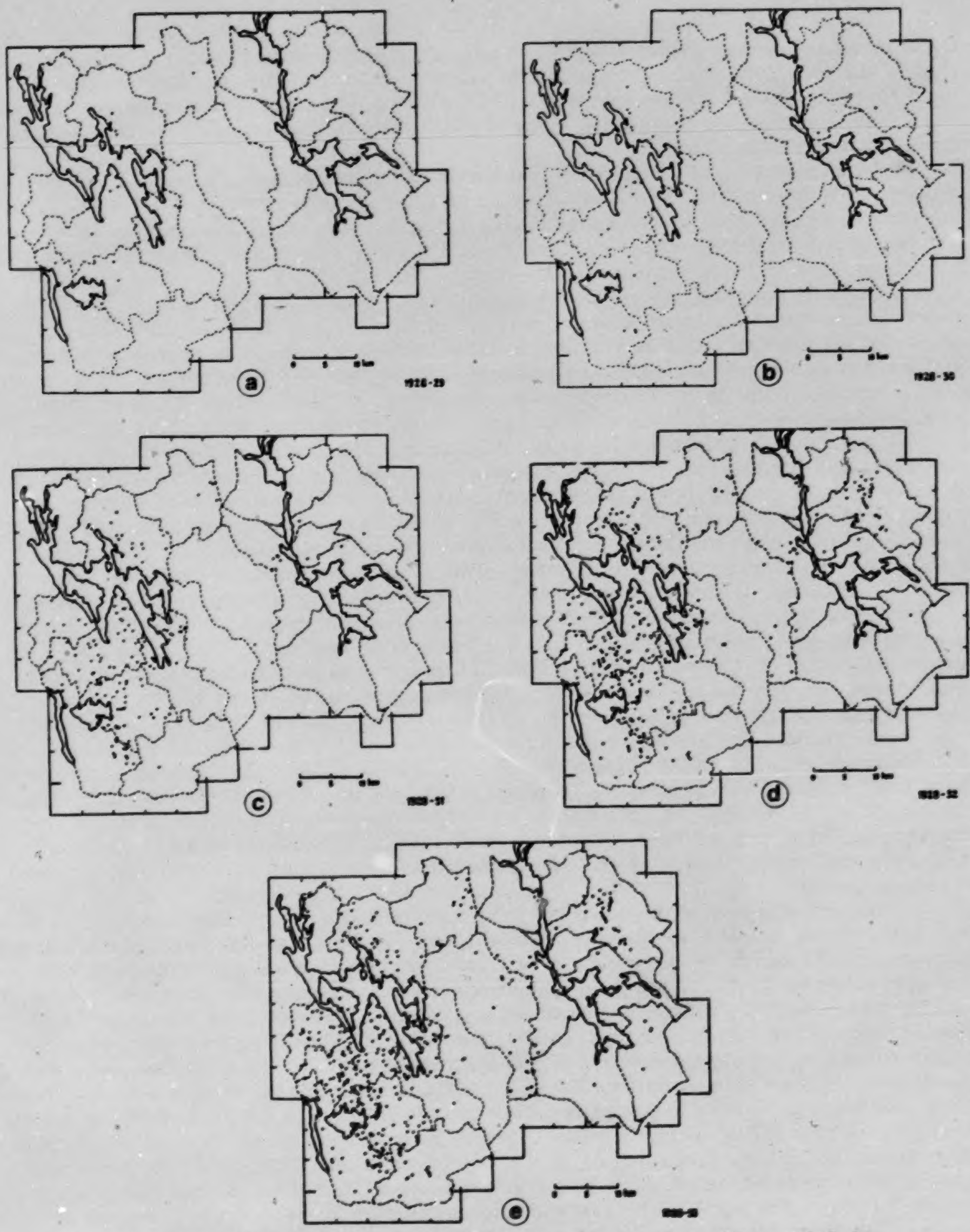

0 5 10 km
a
1928-29
0 5 10 km
b
1928-30
0 5 10 km
c
1928-31
0 5 10 km
d
1928-32
0 5 10 km
e
1928-33

FIGURE 33a-e. Diffusion of pasture improvement subsidies, 1928-33 (adapted from Hägerstrand, 1953)

Let us first consider the pieces of the problem and simplify some of them to make this first step in model-building as easy as possible. The process of simplification is not just important but is essential: it is easy to make things difficult, but very hard to make things simple. If we can simplify a problem in the beginning by making some assumptions, we can always make it more complicated later if we are dissatisfied by our first attempt.

Our first assumption, then, is that the proportion of potential adopters is spread evenly over the land and that a message or an innovation can move with equal ease in any direction. We can think of a grid overlaying the map of the region with the same number of potential adopters in each grid cell. Thus our model starts with the assumption of the homogeneous "transportation surface," or, if we like, under isotropic conditions. The next question is: how will messages move? Here we shall assume that news about an innovation only moves by one person coming into face-to-face contact with another and telling him about it. Communication, in other words, is by pair-wise telling, and as soon as a person hears the news we assume that he will adopt the innovation.

Now we come to the core question, the answer to which forms the most important building block of the entire model: how will a person who knows about an innovation be paired with someone who does not? Our last assumption deals with this question by specifying that the probability of a receiver being in communication with a teller depends simply on the distance between them. We would expect the probability of a message passing between two people to be high when they are close together, and small when they are far apart. Thus, we might imagine around each person a "communication field" that was strong close to him but got weaker as it declined with distance (Figure 34). The problem is, how can we measure the probability of a person passing a message over a certain distance? If we take a sample of telephone calls in a region, and plot the number of calls against the distance over which they move (Figure 35), we will get some notion of the way in which the friction of distance cuts down inter-personal communication. By taking the logarithms of the number of calls and the logarithms of the corresponding distances (Figure 36), we get a plot for which the best-fitting, straight line can be found. This shows us the general decline in the intensity of communication with distance, and defines for us the mean information field (MIF) for the area. In some, very simple societies, for example, the slope of the MIF might be quite steep, indicating that most of the time the people only communicate over short distances and that long distance tellings are unlikely. In other, very mobile societies, the slope of the MIF might be shallower, indicating that the probability of communicating over longer distances is greater.

The problem now is to put all the pieces of the model together, translating first our estimate of the MIF into an operational form. We shall assume that the mean information field takes the form of a small, square grid of 25 cells, the sizes of which are the same as those of the grid lying over the map (Figure 37). To each of the 25 cells in the MIF we assign a probability, assuming that the teller is located in the middle cell. Thus the center cell receives a value of 0.4432, so that every time the teller passes a message there are 4,432 chances out of 10,000 that the message will go to someone else in the same middle cell. On the other hand, the corner cells are far away, and the chances of a message passing to people in these remote locations is much smaller. A probability value of only 0.0096 is given, or 96 chances in 10,000. Notice that the sum of all the probabilities is 1.0, or complete certainty, implying that whenever a message is passed it must fall within the mean information field.

To make the probability assignments in each of the cells operational we shall accumulate them by starting in the upper left hand corner and moving row by row to the lower right hand cell. To each cell we assign some four-digit numbers

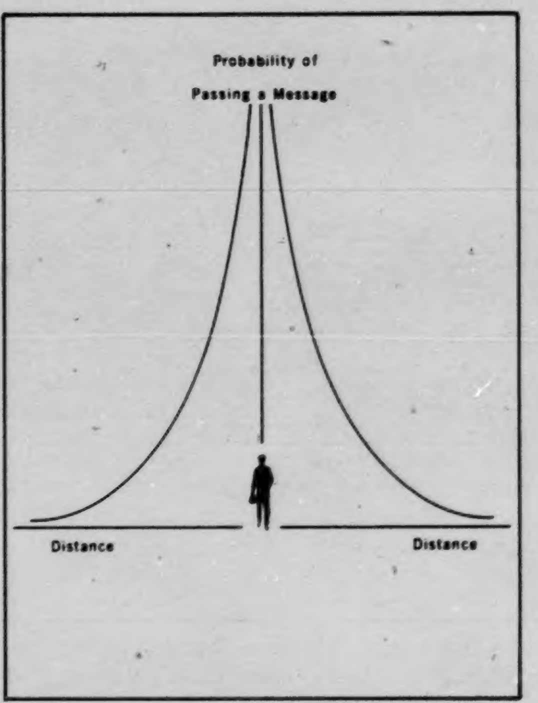

Probability of
Passing a Message
Distance
Distance

FIGURE 34. A personal communication field

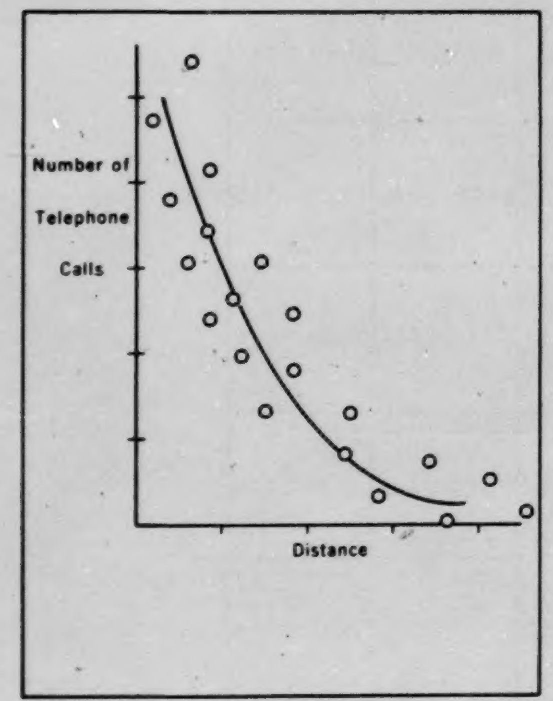


FIGURE 35. Plot of telephone calls against distance

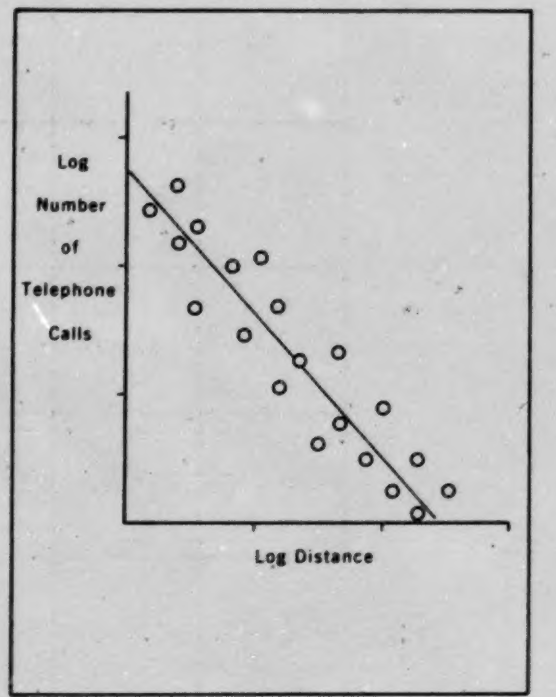


FIGURE 36. A straight-line relationship: log of calls against log of distance

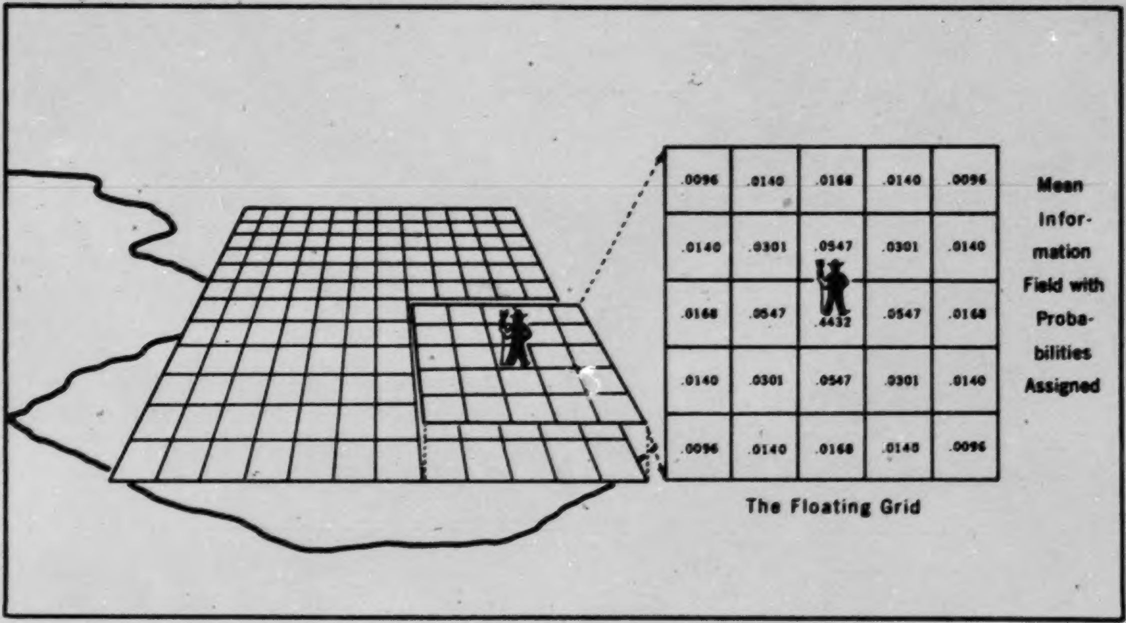

.0096 .0140 .0168 .0140 .0096
.0140 .0301 .0547 .0301 .0140
.0168 .0547 .4432 .0547 .0168
.0140 .0301 .0547 .0301 .0140
.0096 .0140 .0168 .0140 .0096
Mean Information Field with Probabilities Assigned
The Floating Grid

FIGURE 37. The mean information field as a floating grid of twenty-five cells with the probabilities of communication assigned

0-95	96-235	236-403	404-543	544-639
640-779	780-1080	1081-1627	1628-1928	1929-2068
2069-2236	2237-2783	2784-7214	7215-7761	7762-7929
7930-8069	8070-8370	8371-8917	8918-9218	9219-9358
9359-9454	9455-9594	9595-9762	9763-9902	9903-9999

FIGURE 38. Accumulated intervals for mean information field

corresponding to the probability of the cell receiving a message from the center (Figure 38). Thus, in the upper left cell, we have the interval 0000-0095, or 96 four-digit numbers, because P = 0.0096. The next has the numbers 0096-0235 assigned, giving it 140 numbers corresponding to the number of chances in 10,000 of receiving a message. This cumulative process continues until we reach the last cell in the lower right hand corner with the numbers 9903-9999.

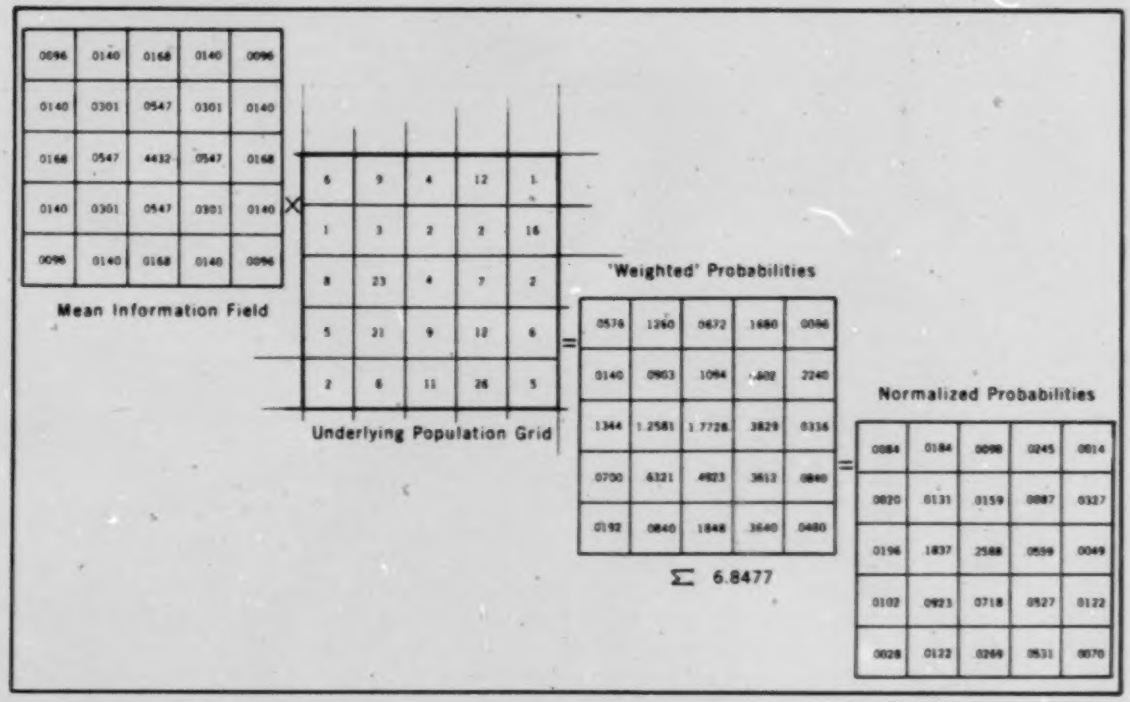
We now have all the pieces of the model, and all we need is a driving force—an engine—to power it. Our source of energy is going to be a stream of four-digit, *randomly chosen* numbers. We can imagine the MIF floating over each of the map cells in turn, stopping at a cell whenever it comes across one of the first few innovators. These are assigned from actual data at the start of the analysis. Whenever it stops over a teller, a four-digit number is drawn at random, and this number locates the cell of the next adopter. For example, if we had the numbers of 0000 to 9999 in a hat, and drew out 7561, then we would know that the innovator had passed the message to the adjacent cell lying just to the east of the middle one. A person in this cell immediately adopts the innovation, and the MIF "having writ moves on," continuing to scan each of the cells of the map in turn, stopping over each innovator, and generating a new adopter of the innovation. One complete pass over the map constitutes one time period or "generation" of the diffusion process. Then the MIF starts again, stopping twice as often during the second generation, four times as often during the third generation, eight times during the fourth, and so on. Of course, random numbers are not really pulled out of hats: random number tables are available in published form, and today these models are programmed for large computers which have special means of generating random number series.

As one generation of telling follows another, a pattern of diffusion will be developed from the initial assignment of the first few innovators to the population cells. It is for this reason that this type of diffusion model is termed a *simulation* model, for it simulates a process acting through time and over space. Notice, also, that every time we run such a model we will get a slightly different result; the diffusion pattern from one run will not match another run exactly. This is because our model is also *probabilistic* in nature, for we used probabilities in the mean information field, and generated every new innovator by the chance, or probabilistic process of drawing random numbers. This way of powering a simulation model is known as the *Monte Carlo method*, so our complete diffusion model is known as a *Monte Carlo simulation model under isotropic conditions*!

The model is very simple and can easily be run by hand with a map of grid cells, a table of random numbers, and a small plastic overlay with 25 cells for a MIF. As it stands, however, it is not terribly realistic. Innovations do not diffuse geometrically in the 2-4-8-16-32 fashion, but begin to slow down as saturation levels are reached. One way to make the model more realistic would be to identify each potential adopter in each of the grid cells overlaying the map. Let us suppose that there are 10 potential adopters in each cell. Every time a teller got the MIF, and generated a new message to another cell, we could draw a second, single-digit random number between 0-9. If the person, say Mr. Seven, has not been "hit" before, we would make him adopt then and there. But if he had been drawn before and already had the message, the second hit would be wasted upon him. The MIF would move on without generating a new adopter that time. In the early stages the pattern of diffusion would develop quickly, but during the later time periods we would be getting close to saturation and a number of new pulses of information would be wasted on the people who already had the news. Thus the diffusion process would slow down, producing the much more realistic S-shaped diffusion curve of adoption. Of course, adding this additional requirement to the model would involve a lot of bookkeeping, but when simulation models are programmed for a modern computer, this is no longer a problem.

Another way of making the model more realistic is allowing the population to vary from cell to cell on the map. This seemingly simple addition to the model also produces some very tedious arithmetic operations. Suppose, for example, that the MIF lands on a teller surrounded by an unevenly distributed population. Realistically, the probability in each cell should change, being weighted by the number of people in each map cell who are potential adopters. We can weight the probabilities in the MIF by multiplying each one by the corresponding population in the underlying cell on the map (Figure 39). Having multiplied through, the sum of the "weighted probabilities" is now greater than 1.0, so we must divide each value by this total to "normalize" our MIF. When this is done, the probabilities add up once again to 1.0, and we can assign the corresponding intervals of four-digit numbers once again. It is a simple, but extremely time-consuming process if you think that this has to be done for every teller before every telling! Again, computers can come to our aid to perform such dull, but simple arithmetic.

Barriers may also be introduced. Between some grid cells on the map we may assign absolute or absorbing barriers, so that when an MIF tries to generate a message to a cell lying on the leeward side the telling is disallowed. Or we can assign barriers to our map with varying degrees of permeability – again on a probabilistic basis. For example, if a barrier is 50 percent permeable, and a message is generated by a teller across it, we could flip a penny and allow the telling only if it lands heads.



Mean Information Field

0096	0140	0168	0140	0096
0140	0301	0547	0301	0140
0168	0547	4432	0547	0168
0140	0301	0547	0301	0140
0096	0140	0168	0140	0096

Underlying Population Grid

6	9	4	12	1
1	3	2	2	16
8	23	4	7	2
5	21	9	12	6
2	6	11	26	5

'Weighted' Probabilities

0576	1260	0672	1680	0096
0140	0903	1094	0602	2240
1344	1.2581	1.7728	3829	0336
0700	6321	4923	3612	0840
0192	0840	1848	3640	0480

Σ 6.8477

Normalized Probabilities

0084	0184	0098	0245	0014
0020	0131	0159	0087	0327
0196	1837	2588	0559	0049
0102	0923	0718	0527	0122
0028	0122	0269	0531	0070

FIGURE 39. Weighting the probabilities with the underlying population

Alternatively, we could generate another random number, and allow the telling only if it were an even one. Assigning a number of absorbing and permeable barriers would slow down the course of a diffusion simulation, matching the process in the real world under similar conditions.

Finally, we can add psychological barriers to our model. If we assume that the chances of adoption change according to the number of tellings, then we can convert a probability distribution of tellings into a number of two-digit intervals (Figure 40). With a computer keeping track of both the person in the cell and the number of times he has been hit previously, we can generate a two-digit random number before deciding whether the new adoption has taken place. Suppose, for example, that the MIF has contacted Mr. Three in a particular cell and he has been hit once before. The first time the number 89 was drawn; and, as it did not lie in the interval 0-4, Mr. Three did not adopt. The second time, however, the two-digit number 24 is chosen. This lies in the interval 5-24, so Mr. Three adopts the innovation and becomes a teller himself at the time of the next generation.

How well do such models simulate actual diffusion processes? Let us take the spread of pasture improvement subsidies once again (Figures 33b-e) and simplify them by recording the adopters in each cell (Figures 41a-d), adding some absolute barriers (solid lines) and others of 50 percent permeability (dotted lines). These barriers represent the effects of the long lakes that lie in the region and thwart communication. Using these barriers, and assigning the actual number of potential adopters to each cell, produces anisotropic conditions in the model that closely resemble the real world. When a computer simulated the diffusion of pasture subsidies under these conditions,

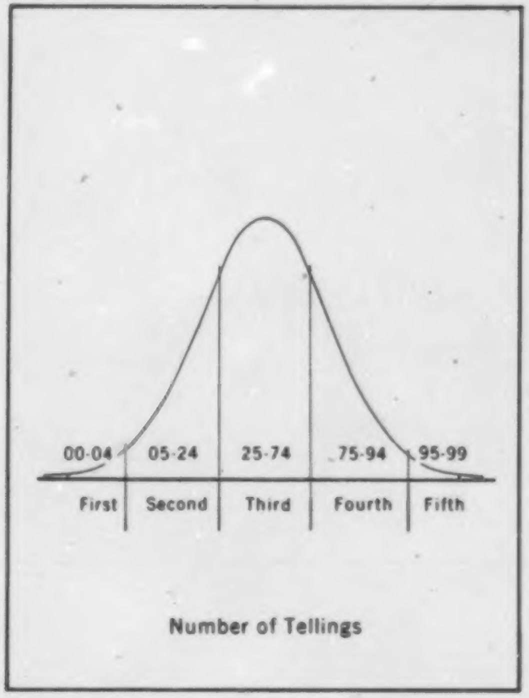
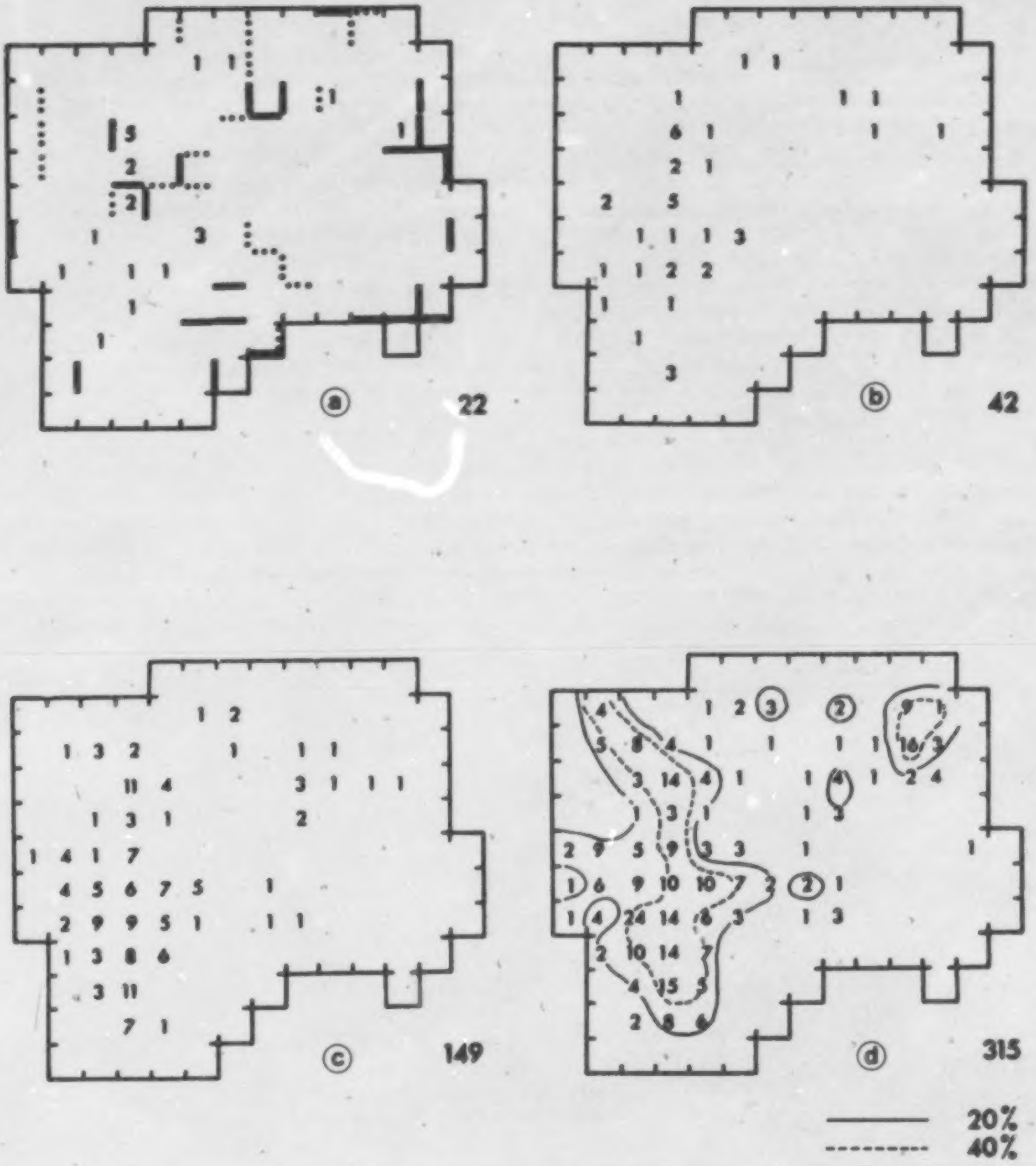


FIGURE 40. Accumulated intervals for the number of tellings

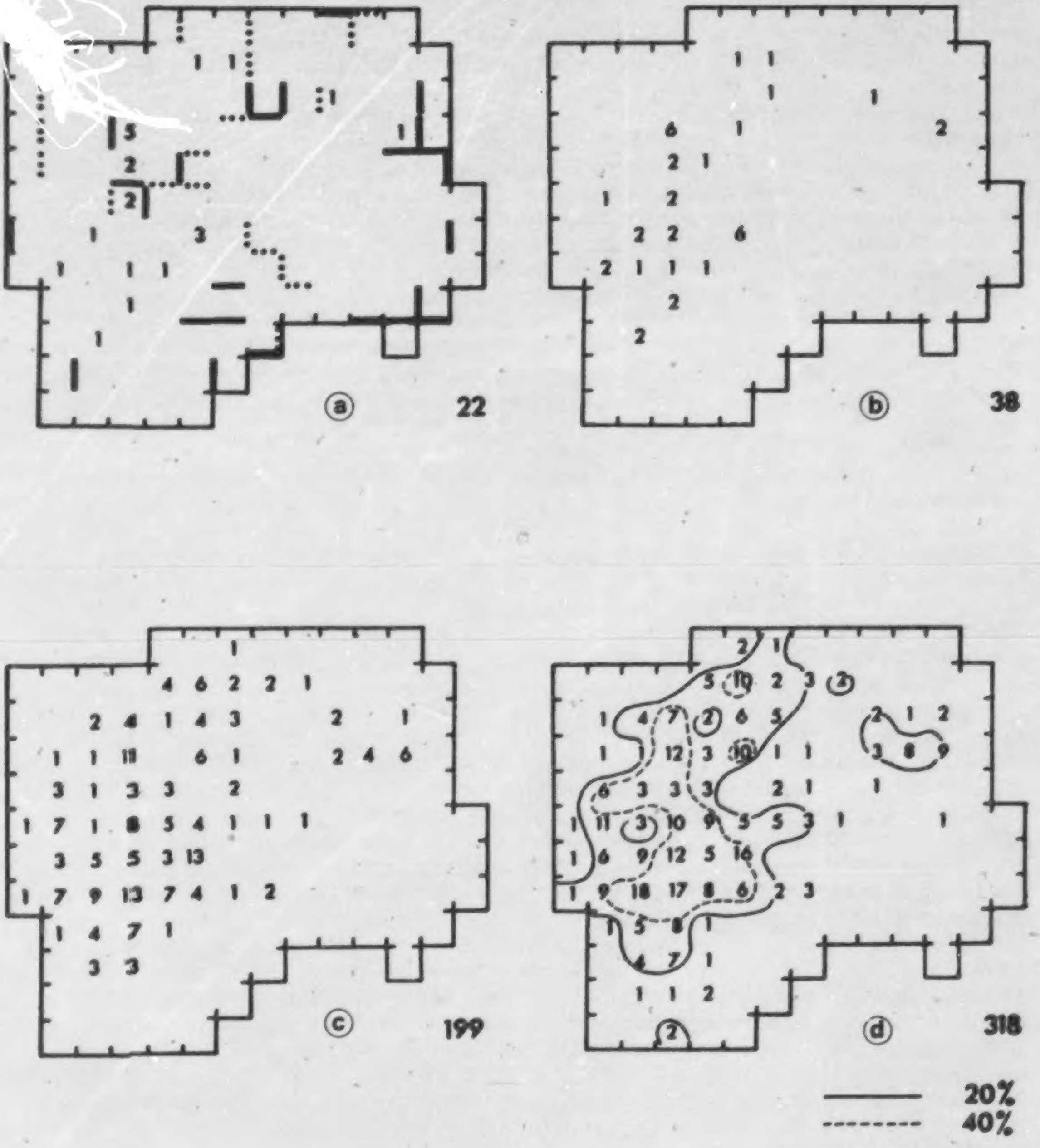

a
22
b
42
c
149
d
315
20%
40%

FIGURES 41a-d. Actual diffusion of pasture subsidies (from Hägerstrand, 1965) the patterns that were developed by the Monte Carlo method closely resembled the actual conditions (Figures 42a-d). A comparison of the final output (Figure 42d) with the last map in the real sequence (Figure 33e) indicates how closely the simulated and the actual patterns coincide, particularly when we remember that we are dealing with a probabilistic process. The isolines enclose areas where 20 percent and 40 percent of the potential adopters have accepted the pasture innovation, and both patterns display the major clusters resulting from a rapid diffusion in the west, while the eastern outliers also correspond reasonably closely. The testing of spatial simulation models poses difficult and still unsolved problems in an area of applied mathematics known as inferential statistics. However, it seems likely that our present visual comparisons and judgments will stand up well when more sophisticated methods come along.

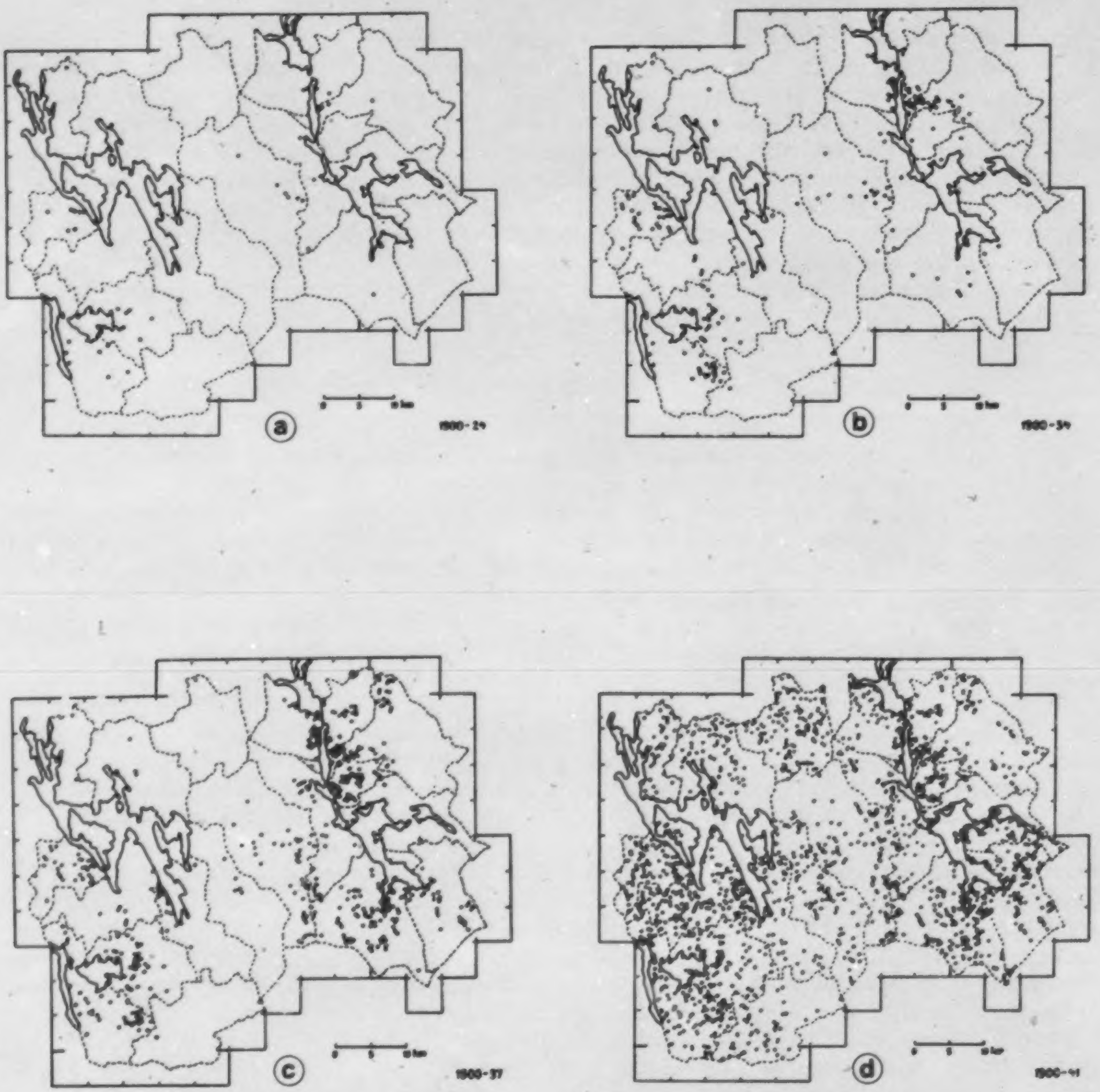
No matter what the starting configuration, many patterns of diffusion at the micro-level consistently display an uncanny regularity and order as they gradually unfold upon the landscape. In the same area as the pasture subsidy, Hägerstrand also examined the spread of other innovations such as TB control in dairy cattle, soil mapping, automobile ownership, postal checking accounts, and telephones. The acceptance of TB control (Figure 43a) involved considerable sacrifice on the part of the farmers, for diseased cattle were slaughtered, and the diffusion proceeded much more slowly than the pasture subsidy. Distinct spurts in acceptances occurred as price supports were passed for the purchase of TB-free milk. By the end of 1924, nearly 60 farms had tuberculin-tested dairy herds, and these formed distinct clusters in the southwest and northeast, with a few scattered innovators. A large area empty of acceptors sliced diagonally across the area from north to south. By 1934, after 10 years of diffusion, the innovation had made considerable progress (Figure 43b). Over 200 farms in the area had accepted, the original clusters had thickened and expanded to form the typical nebula-like pattern so characteristic of innovation movements, and a "bridge" of acceptors was being formed across the middle area as the farms were battered from two sides! The pattern for 1937 (Figure 43c), confirms the regularity of the process as the innovation pushed outward from the original core areas, particularly in the southeast where farmers accepted with a rush, after the price of TB-free milk went up. By 1941 (Figure 43d), the process was almost complete as the "laggard areas," far from the initial clusters, finally accepted the innovation.

Lest you think that only Swedish spatial behavior is orderly and predictable, we are going to turn to the United States as a final example of diffusion at the individual or micro-level. The northern high plains of Colorado, immediately to the east of Denver, have traditionally been an area of dry land farming and cattle grazing. During the late 1940's and early 1950's, many of the farmers tried to enlrage their cattle feeding facilities, but a series of droughts hammered the area and getting sufficient feed for the large herds became a severe problem. Some of the farmers began to turn to irrigation, installing wells and pumps to tap the groundwater, even though this often involved heavy outlays of capital up to $40,000. By 1948, 41 wells had been sunk (Figure 44a). That pump irrigation was possible was well known throughout the area, but the decision to adopt this new form of farming appears only to have come from actual discussions on a face-to-face basis by the farmers themselves. Once again, we are concerned with the problem of establishing the mean information field for the people of an area. In Colorado, barbecues are big social events and people come to them from miles around. By establishing patterns of barbecue attendance, and supplementing the information with telephone call data, it was possible to estimate the effect of distance upon social communication in this area of scattered farms.

Using procedures similar to Hägerstrand, and starting with the 1948 configuration, the geographer Bowden simulated the diffusion of 410 wells (Figure 44b), which


a
22
b
38
c
199
d
318
20%
40%

FIGURES 42a-d. Simulation of pasture subsidy diffusion (from Hägerstrand, 1965)



0 5 10 km
a
1900-24
b
1900-34
c
1900-37
d
1900-41

FIGURES 43a-d. TB control in dairy cattle 1900-41 (from Hägerstrand, 1953) was the number of actual wells that had been adopted by 1962 (Figure 44c). So close was the average of 10 simulated runs to the pattern in the real world, that the model was used as a predictive device. The actual 1962 configuration was used as a new starting point to simulate the expected pattern in 1990 (Figure 44d). An additional "rule of the game" was also provided, specifying that no more than 16 wells could be drilled in any one township (S-S-S area of the map). By 1990, a total of 1,644 wells are expected, drawing 20 million acre feet of water from the groundtable every year. Only time will tell whether the actual course of diffusion will proceed in this way, but one aspect of the model has proven itself already: the rule of no more than 16 wells per township has been adopted as a result of the geographical study. Sometimes roles are reversed, and the real world conforms to the geographer's model!

Changing the Scale: Urban Aspects of Diffusion

As we change scale and move up the cone of resolution, agglomerations of many individuals become the next focus of our diffusion processes. The modern world is increasingly an urbanized world as the vast compactions of men, together with their concrete, steel, and asphalt works, gradually ooze from the earlier cores of intense settlement. "Ooze," of course, is a relative term, for its use to describe the flow of cities into the countryside depends upon our perception of time. Sometimes the diffusion of a city seems almost explosive. In 1840, London was a city not more than 5 miles across with about two-thirds of it on the north bank of the Thames (Figure 45a). Even in 1860 (Figure 45b), it still appeared very compact, although this only proved to be the bucolic lull before the urban storm. By 1880 (Figure 45c), with the Industrial Revolution sparking the drive and new fangled railways reaching out like tentacles into the commuter countryside, London had started to explode. By 1900 (Figure 45d), it was throwing ahead of its advancing waves burgeoning dormitory towns that were later enveloped by the great urban mass. The year 1914 (Figure 45e) already saw many of the dormitory towns that had once been villages linked into continuous urbanized strips. As more and more fields and woodlands were devoured by the metropolitan giant, men tried to develop institutional barriers against the seemingly inexorable diffusion process. Parklands were set aside, and "Green Belts" laid out where building was strictly controlled. Today (Figure 45f), the built up area is 40 miles across, and commuter line tentacles influence development as far as 50 miles from the center. Legally the towns surrounding London are separate and distinct: geographically they are but pieces in the ongoing process of spatial diffusion. In America the same process is even less controlled, and today many of the original nuclei on the Eastern Seaboard have diffused outward, coalesced, and given birth to a new phenomena in Man's history – Megalopolis.

Within cities rather similar processes of diffusion also occur, and many of the distinct ethnic patterns of residence are the result of gradual movement outward from a core area – often against strong psychological barriers of racism. In a part of Seattle, for example, a distinct Negro ghetto has developed from a small core area consisting, in 1940, of a score of blocks at the junction of two main thoroughfares (Figure 46a). With natural increase and in-migration, the burgeoning population had to expand outward, and by 1960 (Figure 46b) the core had diffused in a very regular and compact fashion to about 140 residential blocks. "Rules of the Game" may be a hideous misnomer for specifying the factors underlying a spatial process with such distressing human consequences, but when a number of well-specified forces are linked together in a simulation model they do seem to account for the spread of the ghetto. Using a mean information field to generate the probability of house-searching contacts,

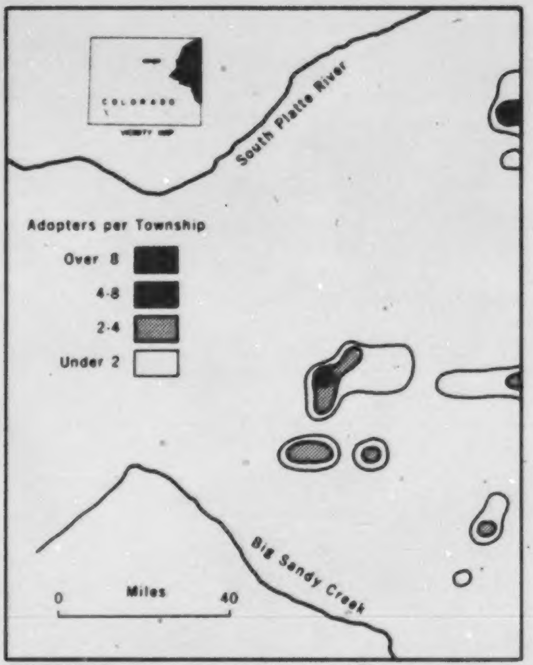

COLORADO
VICINITY MAP
South Platte River
Adopters per Township
Over 8
4-8
2-4
Under 2
Big Sandy Creek
0
Miles
40

FIGURE 44a. Irrigation wells per township: actual pattern, 1948 (adapted from Bowden, 1965)

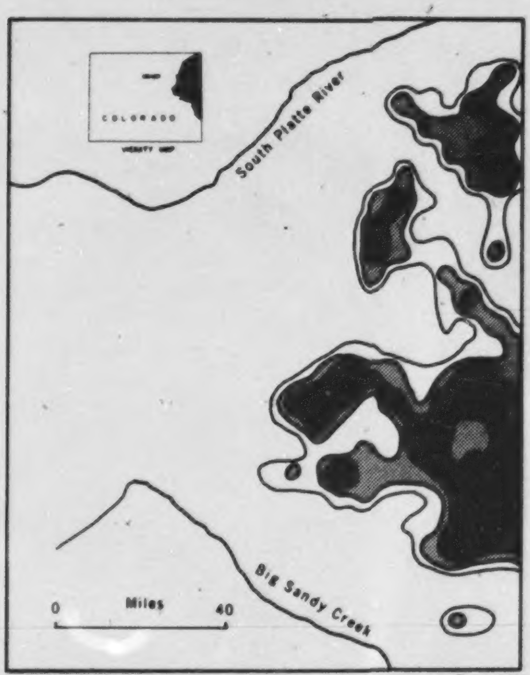

COLORADO
VICINITY MAP
South Platte River
Big Sandy Creek
0
Miles
40

FIGURE 44b. Simulated pattern of 410 wells (adapted from Bowden, 1965)

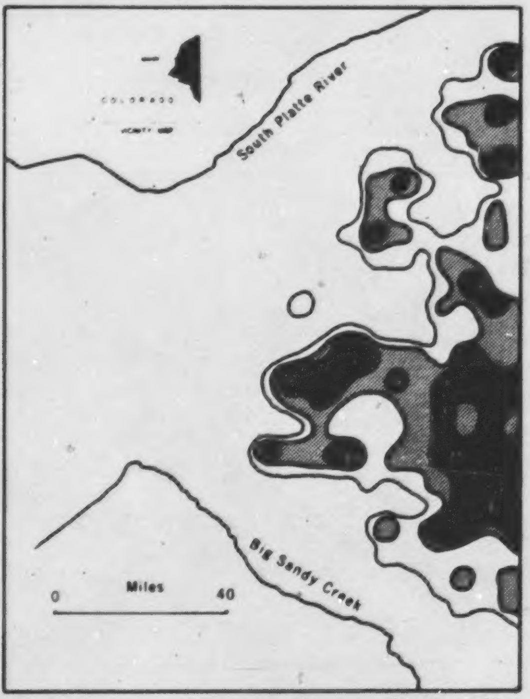

COLORADO
VICINITY MAP
South Platte River
Big Sandy Creek
0
Miles
40

FIGURE 44c. Actual pattern of 410 wells by 1962 (adapted from Bowden, 1965)

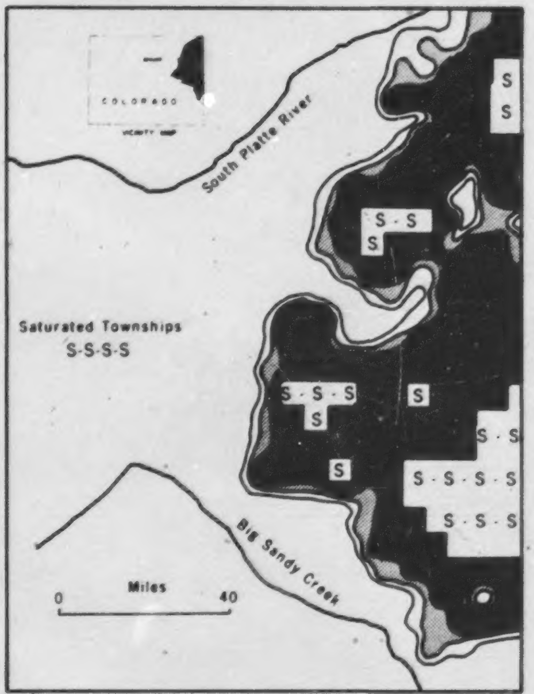
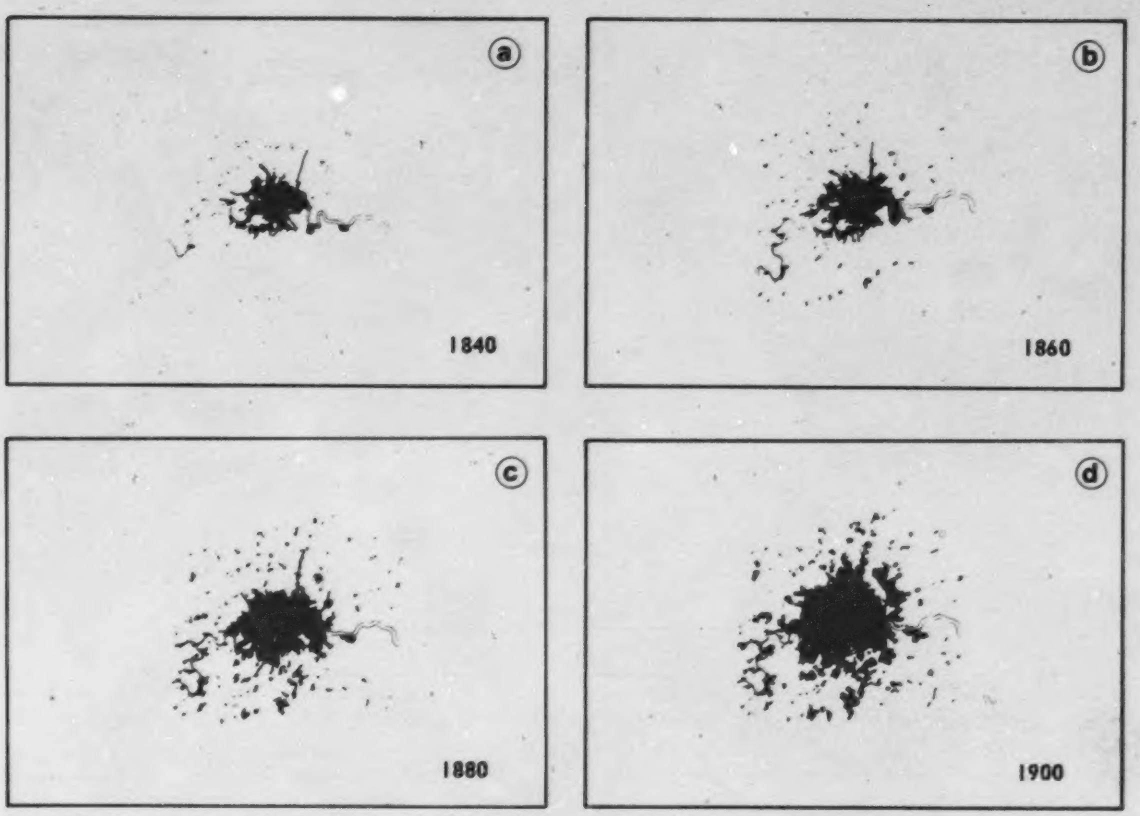

COLORADO
VICINITY MAP
South Platte River
Saturated Townships
S-S-S-S
S
S
S - S
S
S - S - S
S
S
S
S - S
S - S - S - S
S - S - S
Big Sandy Creek
0
Miles
40

FIGURE 44d. Simulated prediction for 1990 (adapted from Bowden, 1965)


a
1840
b
1860
c
1880
d
1900

FIGURES 45a-e. London in 1840-1914 (adapted from Rasmussen, 1967)

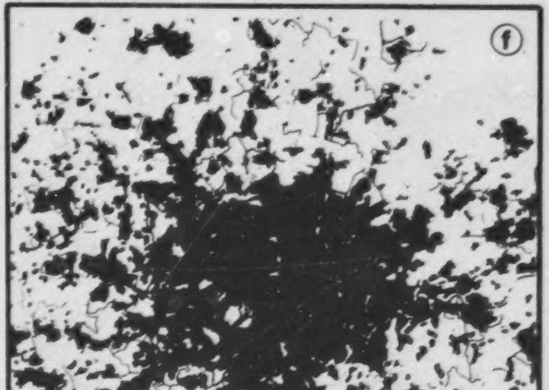


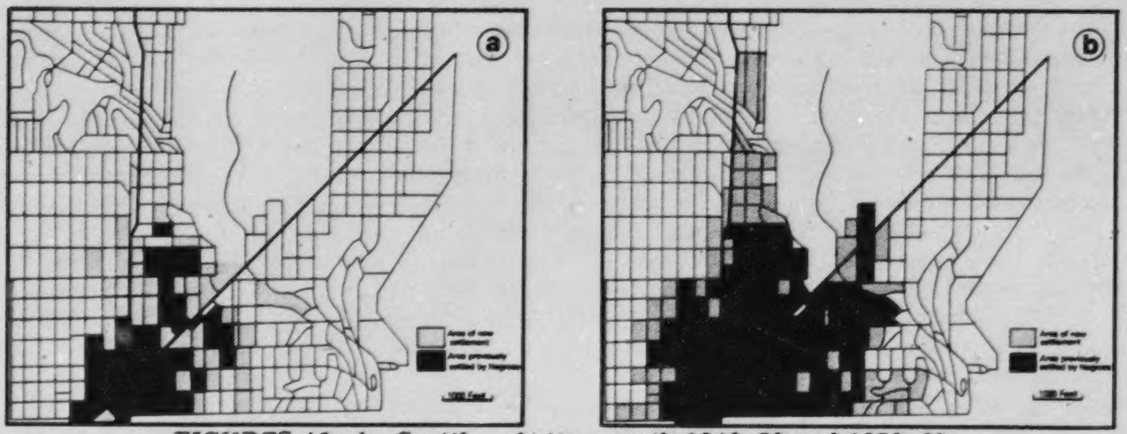
FIGURE 45f. London in 1964 (adapted from Smailes, 1964)

estimates of in-migration and natural increases, and rules for specifying the number of randomly generated contacts required for "block-busting," Richard Morrill simulated the diffusion of the ghetto over a quarter of a century (Figures 46c and d). Visually there appears to be a very close correspondence between the simulated and actual pattern, indicating that most of the general aspects of the process have been incorporated into the model. A typical two-year "generation" in one of the simulations over a ten-year census period shows how each of the old locations generates new contacts and entries into blocks that have been "busted" (Figure 46e). To the west, resistance from whites was very high, and many contacts had to be generated by the MIF before entry was allowed. A final simulation for the period 1960-64 (Figure 46f) indicates how this barrier of prejudice biases the spread of the ghetto to the east and north—both areas where resistance of white real estate operators and residents was less than to the west.

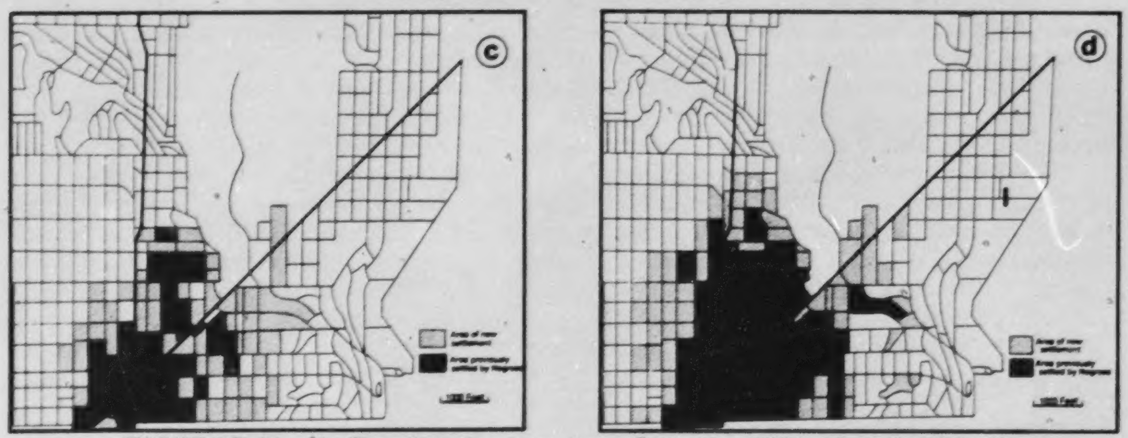
The process of block busting is a rule of spatial diffusion we have not met before that implies the notion of a threshold. Whereas psychological barriers at the micro-level were never absolute, for we allowed the possibility of acceptance even on the first contact, in the ghetto simulation the rules specified that at least a certain number of contacts had to be made before block busting occurred. A certain threshold value had to be reached before the barrier crumbled. Somewhat similar problems were encountered in a study of linear diffusion of billboards along the four main arteries leading from State College, Pennsylvania (Figures 47a-d), a typical university town that has grown rapidly since the Second World War. In 1953, billboards tended to cluster close to the town where traffic density was highest. Four years later the town fringe expanded north and south, and billboards had to be relocated near the head of the advancing urban wave. In 1961, the former clusters were much thicker, and by 1965 the beautiful approaches, over gently rolling country leading to vistas of hills beyond, resembled the typical "billboard alleys" that lead into most of America's towns and cities. Probabilitistic rules to simulate such a diffusion process were complex, and included (1) probabilities assigned according to distance from the center, (2) removal rates conditioned by the growth of the town, (3) saturation limits, (4) "barrier farmers" who preferred a beautiful countryside, and (5) a series of threshold values for each parcel of land along the highway. The threshold values changed as the diffusion process was simulated by the computer to allow for the effects of spacing and "visual competiton." In the first simulated time period (Figures 48a-d), the model appears to generate the available boards over a greater length of road than the actual, but as the process unfolds the conformity between the two sequences appears much stronger. Route 322 North and the Benner Pike as of 1965 are closely approximated, although the other two routes conform less well. The model over-predicts the density of billboards close to the town on Route 45, for in the real world a small airport has a barrier effect upon the actual course of diffusion. On 322 South, a series of small dormitory villages distorts the pure field effect of distance from State College, and secondary nodes of billboard diffusion appear.

Another Change of Scale: Diffusion at the Regional Level

As we move further up the cone of resolution and examine diffusion processes at larger geographic scales, we tend to blur and smooth individual effects by lumping many human decisions together. For example, we can think of the diffusion of pioneer settlement over an area as the result of a myriad of quite unique decisions by individuals and their families. But despite the uniqueness of every decision, we may still be able to find considerable regularity and order in the aggregate patterns of spatial behavior.



FIGURES 46a-b. Seattle: ghetto growth 1940-50 and 1950-60 (adapted from Morrill, 1965)



FIGURES 46c-d. Simulated expansion of ghetto, 1940-50 and 1950-60 (adapted from Morrill, 1965)

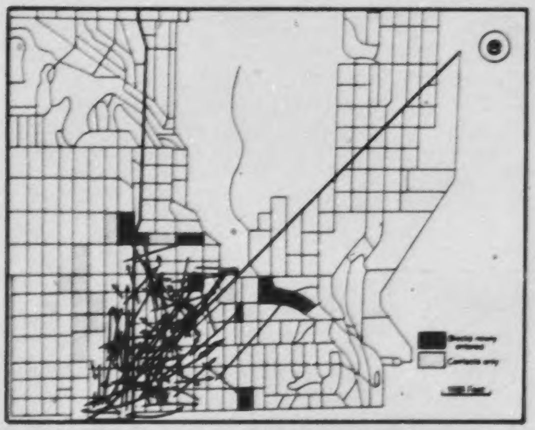


FIGURE 46e. A two-year stage in a ten-year simulation (adapted from Morrill, 1965)

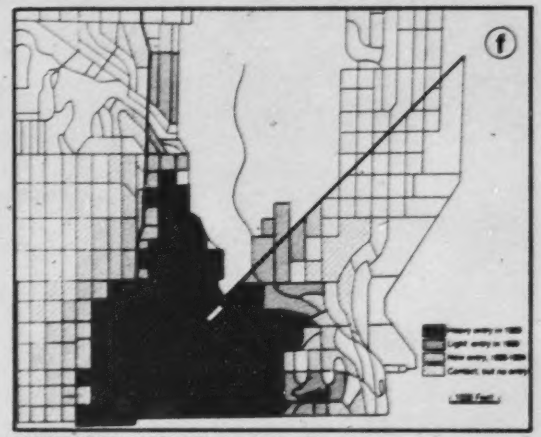
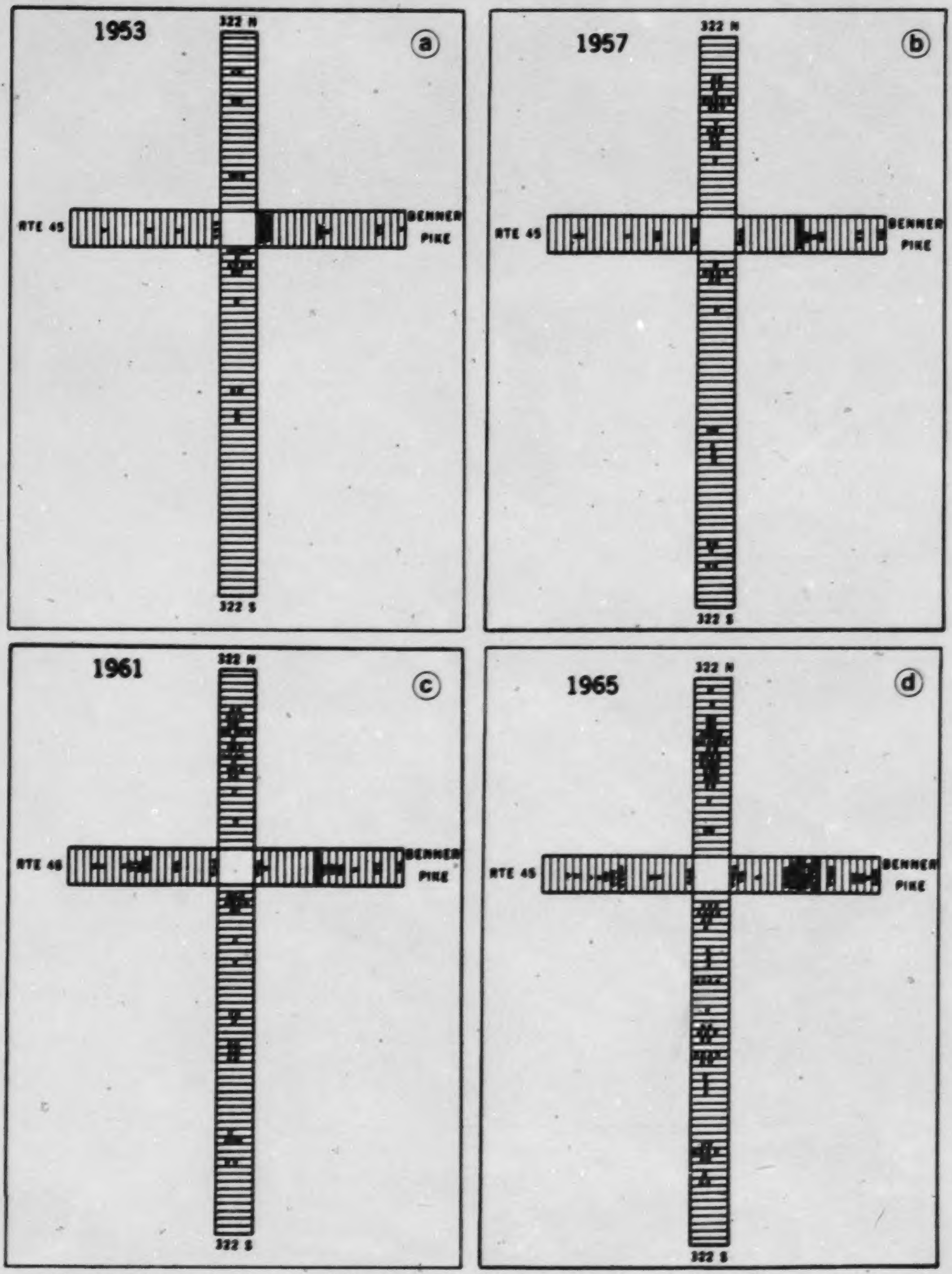
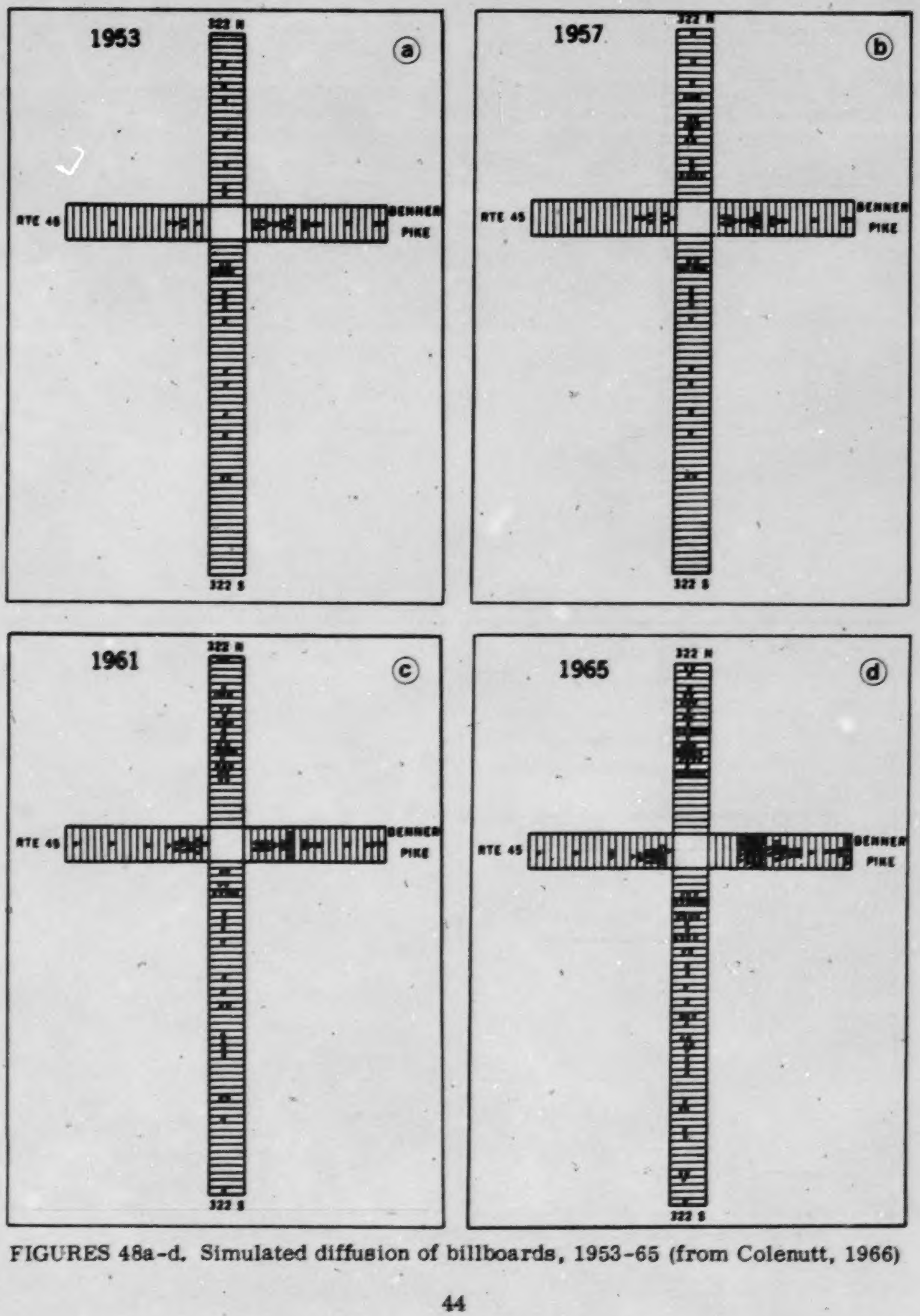


FIGURE 46f. Simulated expansion of ghetto, 1960-64 (adapted from Morrill, 1965)


1953
a
322 N
RTE 45
BENNER PIKE
322 S
1957
b
322 N
RTE 45
BENNER PIKE
322 S
1961
c
322 N
RTE 45
BENNER PIKE
322 S
1965
d
322 N
RTE 45
BENNER PIKE
322 S

FIGURES 47a-d. Actual diffusion of billboards from State College, 1953-65 (from Colenutt, 1966)


1953
ⓐ
322 N
RTE 45
BENNER
PIKE
322 S
1957
ⓑ
322 N
RTE 45
BENNER
PIKE
322 S
1961
ⓒ
322 N
RTE 45
BENNER
PIKE
322 S
1965
ⓓ
322 N
RTE 45
BENNER
PIKE
322 S

FIGURES 48a-d. Simulated diffusion of billboards, 1953-65 (from Colenutt, 1966)

Consider the diffusion, or migration, of people across Pennsylvania from the time of William Penn's first settlement in the 17th century to the beginning of the 19th. We can think of Pennsylvania lying in a three-dimensional graph (Figure 49), in which the two horizontal axes are latitude and longitude, while the vertical represents time of settlement. The 1,500 townships could be plotted as points in our three-dimensional graph according to their spatial and temporal coordinates. We could think, perhaps, of the points as round pinheads stuck into Pennsylvania with pins of varying length. Small pins cluster close to Philadelphia, for these townships were settled early; large pins appear in the northeast. In the same way that we can find a "best-fitting line" to a scatter of points on an ordinary piece of graph paper, so we can get a "best-fitting plane" to all our space-time pinheads (Figure 50). We allow the surface linking time and space to warp, and its projection onto the map produces the "diffusion waves" of pioneer settlement. The closeness of fit is about 70 percent, and with such an extraordinarily high degree of regularity to the diffusion process we can come very close to predicting a township's time of first settlement if we know its locational coordinates.

Of course, a simple warped plane does not pass exactly through every point in the graph, and we can plot on a new map the degree to which each township is above or below our time-space plane (Figure 51). Towns, or pinheads, below the plane were settled before the overall trend, while points above were settled somewhat later. The pattern of the extremely high and low anomalies discloses some of the other things besides simple location, or distance from the diffusion source, that we must take into account in our model. Obviously, one reason that some townships did not fall on the

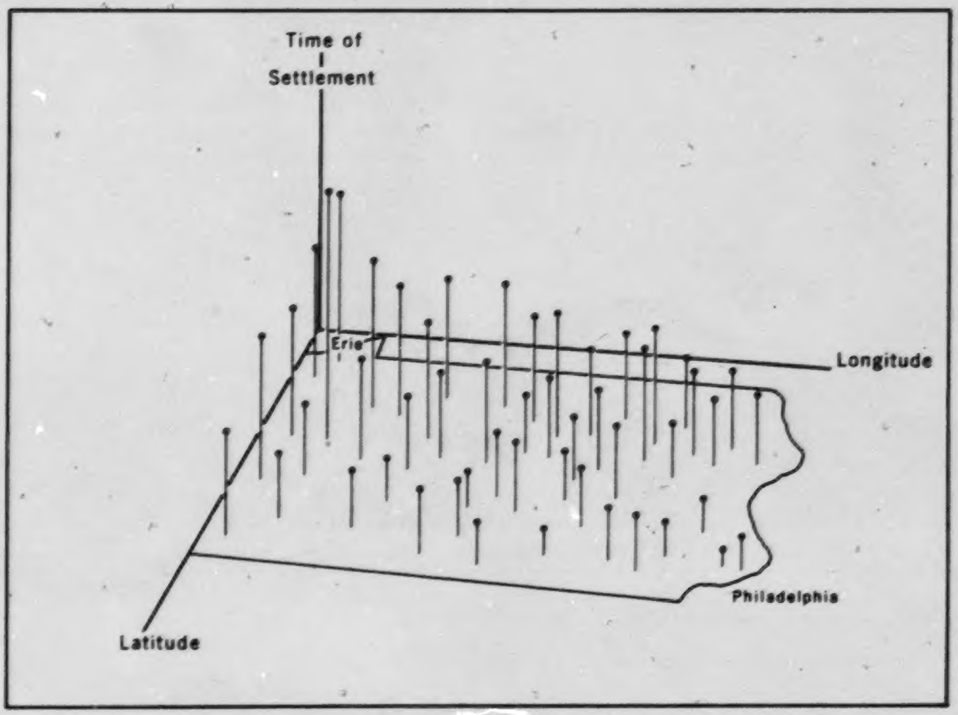


FIGURE 49. Pennsylvania lying in a three-dimensional time-space graph

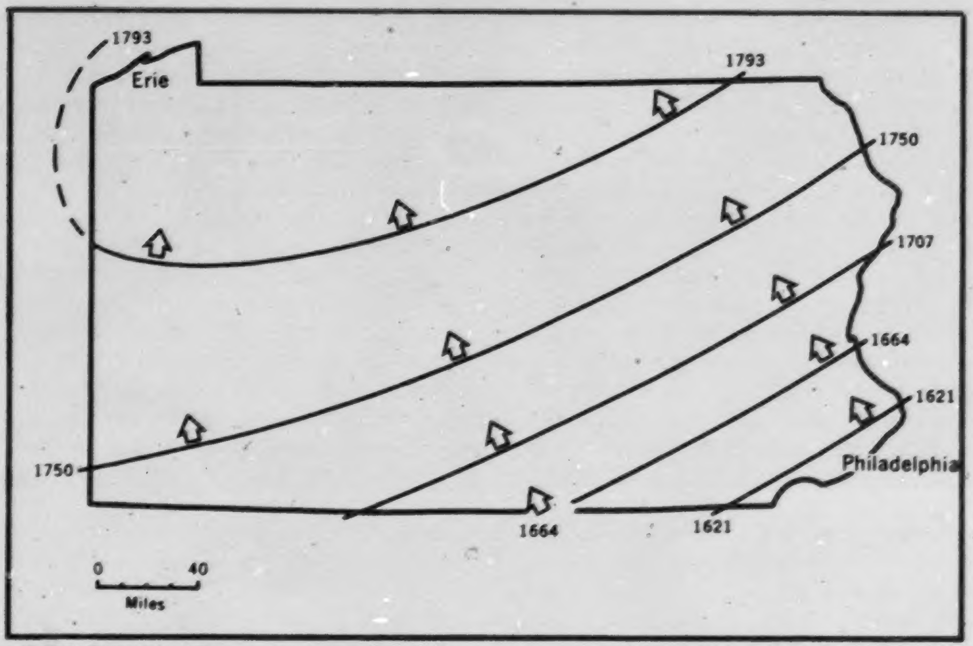

1793
Erie
1793
1750
1707
1664
1621
Philadelphia
1750
1664
1621
0
40
Miles

FIGURE 50. Time waves of settlement across the space of Pennsylvania (from Florin, 1965)

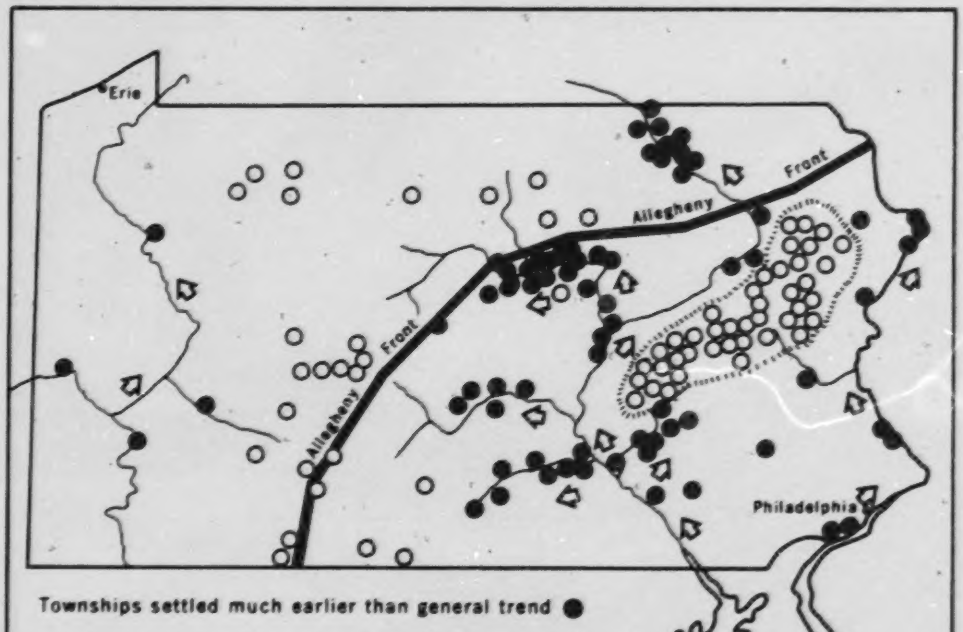

Erie
Allegheny
Front
Allegheny
Front
Philadelphia
Townships settled much earlier than general trend ●
Townships settled much later than general trend ○

FIGURE 51. Townships of Pennsylvania settled much earlier or much later than general trend

curved plane of best fit is because rivers provided faster moving channels for the diffusion process. Many townships on the Delaware, Susquehanna, and Ohio river systems were settled "before they should have been!" On the other hand, there were also clear barriers to the diffusion process. The Allegheny Front and the parallel ridge and valley section to the southeast of it clearly warped the whole settlement wave. Many of the townships settled later than expected lie on the leeward side of these barriers. You can also see this drag effect in the way the time waves get farther apart, and how the last one begins to curl around the southern end as the movement sweeps across the face of the land. An even more distinct cluster of late townships appears in the southeast on the infertile and rugged Pocono Plateau. Clearly, the historical clichés have some merit, but they are only exposed after the strong general trend of the diffusion is slipped out to highlight the local exceptions.

Sometimes diffusion processes over large areas are very complex, and the patterns we see on the map are confusing. We say such cartographic patterns are "noisy" – a very useful bit of jargon borrowed from electrical engineering where sharp incoming *signals* may be blurred and distorted by extraneous background *noise*.* To separate signals from noise we need filters – low pass filters to cut out the high frequency noise, or high pass filters to sharpen up a message conveyed by the higher frequencies. For the geographer, the regional trend surface can often perform the same function, filtering out the noisy local effects that obscure crisp regional trends or signals. Around the turn of the century, for example, Czarist Russia experienced many agrarian riots which seem to have started in the southeastern Ukraine and Baltic provinces. These were precisely the areas with small plot sizes, high tenure rates, and an extreme polarization between peasantry and nobility so that feelings of deprivation tended to be very high. When average riot times in the forty-eight provinces are plotted in a three-dimensional graph against location, a simple trend surface uncovers the broad patterns of the diffusion of rioting (Figure 52). The two hearth areas are disclosed, and the broad spacing of the waves indicates that peasant riots spread rapidly between the source areas. From the southern source in the Ukraine, the cry for agrarian reform spread in almost even ripples, like those produced by a stone dropped in a pond, until localized areas of resistance were met in the north and the time gradient steepened. A definite barrier effect seems to have operated in the northwest from the Baltic, for the wave crests are much closer together as the movement leaves the second source area.

A further example of filtering complex diffusion processes to disclose major regional trends comes from northern Tanzania. The area just south of Lake Victoria experienced the rapid spread of cotton-marketing cooperatives over a 15-year period. The original movement was quite spontaneous on the part of some farmers in the peninsula and island district of Ukerewe (Figure 53), but the local dhow and fishing traffic carried the idea across the Speke Gulf to the major lake port of Mwanza where a further early cluster appears. Another, slightly later group, started in a third area just to the east of the major railway line. As soon as the innovation caught hold, the British Trusteeship administration tried to control the spread for both political and administrative reasons. From its earliest years, the movement was used as a political channel because the leadership of such a powerful institution quickly came into the hands of

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*Do not be afraid of *good* jargon, for it can convey very precise meanings to the initiated in a very efficient manner (for example, sailors' jargon in the days of sailing ships when lots of information had to be gotten across quickly in an emergency). Avoid bad jargon like the plague: it usually means that you do not know what you are talking about!

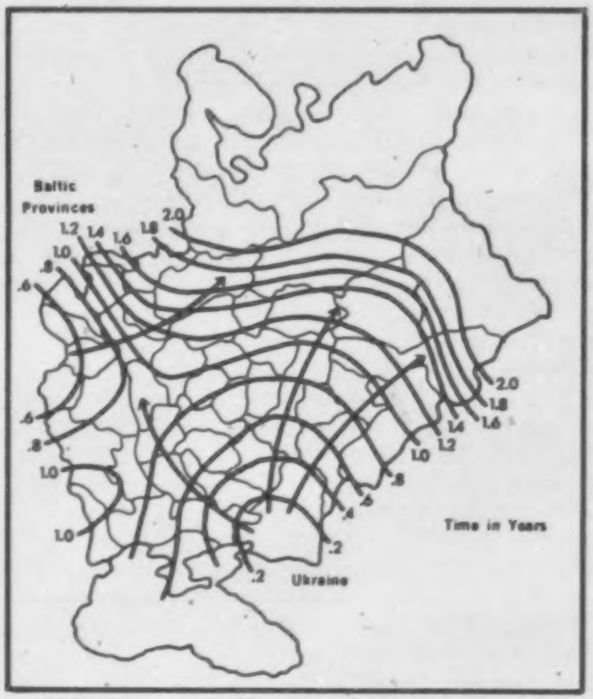
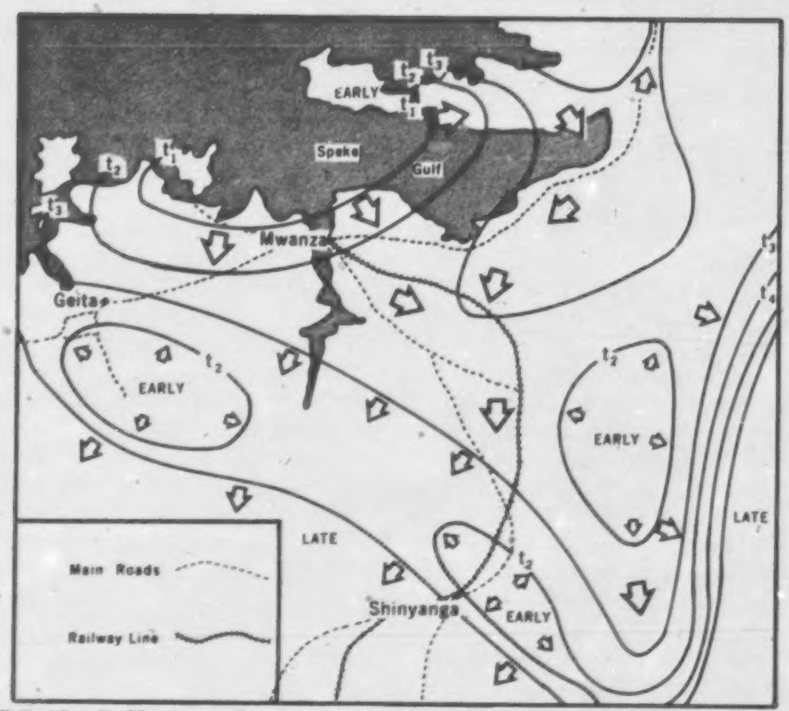


FIGURE 52. Diffusion of agrarian riots in Russia, 1905-07 (from Cox and Demko, 1968)

better educated, urbanized Tanzanians. TANU, the party that led Tanzania to independence, used the network of cooperative communications with great skill, and the TANU flag was often seen outside many cooperative societies in the pre-independence years. Thus we have an example of a political diffusion process following closely on the heels of one triggered by economic considerations.

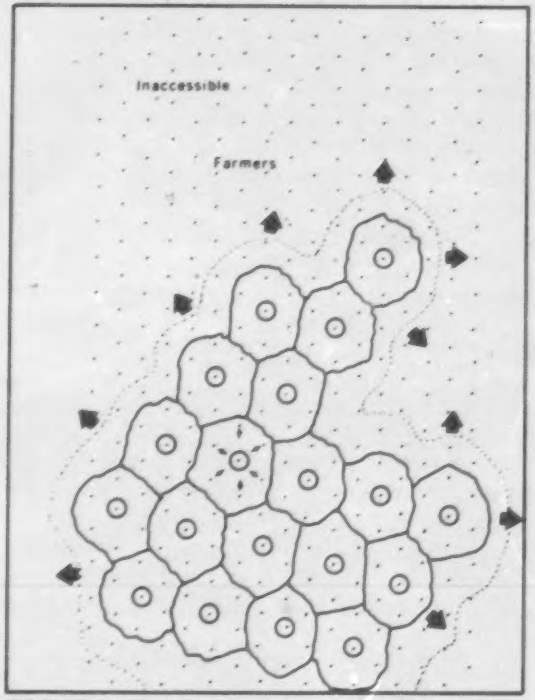
The cooperative movement was also controlled by licensing, and considerable attempts were made to train the treasurers and cooperative officers in the rules of bookkeeping—for the sums of money involved were often very large. Unfortunately, these monetary temptations also injected further noise into the diffusion process. While overall standards of honesty were extraordinarily high, many cases of theft occurred. Individual cooperatives split up so that sets of new officers could be formed who would then have all the prestige accruing to important local men who have their chance of dipping into the till! Many cooperatives were founded much later in areas passed earlier by the initial wave of innovation, and these obscure the overall pattern. At the same time, considerable migration was taking place in the area as new cotton lands were taken up in the eastern part of the region.

We must also remember that a cotton cooperative is a very small, single-function, central place serving the farmers around it. As such, it is a space-competitive institution, for cooperatives will tend to locate far enough away from an established society to gain the minimum, or threshold, membership required. A diffusion of cooperatives completely planned and controlled could pack space tightly from the beginning (Figure 54), gaining in the long run by having no "waste space" to fill later, but losing in the short run by reducing the area of farmers influenced by the idea (dotted



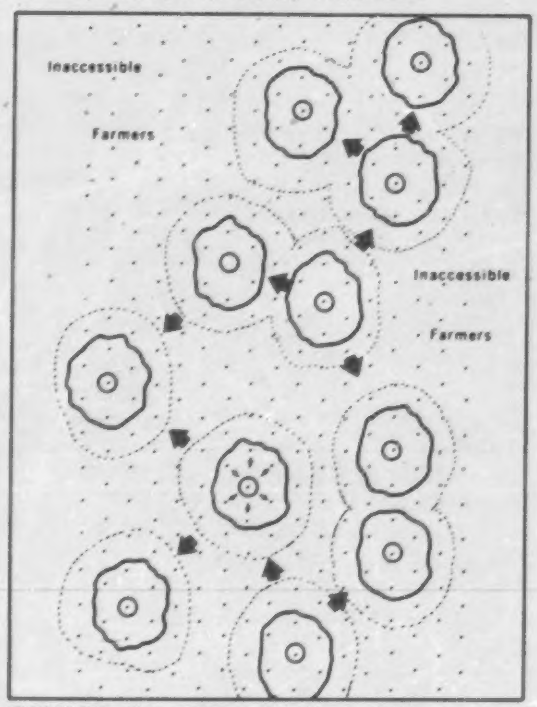
t_3
t_2
EARLY
t_1
Speke
Gulf
t_1
t_2
t_3
Mwanza
Geita
t_3
t_4
t_2
EARLY
t_2
EARLY
LATE
Main Roads
Railway Line
LATE
t_3
Shinyanga
EARLY

FIGURE 53. Diffusion of cotton cooperatives, Lake Province, Tanzania



Inaccessible
Farmers

FIGURE 54. Planned cooperative diffusion packing space tightly



Inaccessible
Farmers
Inaccessible
Farmers

FIGURE 55. Uncontrolled diffusion of cooperatives with inefficient spatial gaps

line). Most cooperative diffusions are not controlled, however (Figure 55); and while in the short run farmers may be influenced more quickly (dotted line again), the overall process may turn out to be spatially inefficient. Farmers in areas caught between existing cooperatives will have to start small and inefficient societies later, or the people will have to carry their cotton many miles for marketing. Thus a system allowed to generate new locations unimpeded may have to develop more societies later to "fill the gaps."

All these considerations – central place, demographic, political, financial, and administrative – are noise obscuring the smooth regional signals. By fitting trend surfaces (Figure 53), we can, however, filter out these elements and see the main pattern. From the early centers in Ukerewe District and around Mwanza, the cooperative idea spread particularly rapidly down the railway, hopping to the large town of Shinyanga, which became a fourth transmitting node. Similarly, in the west, the idea leapt to an administrative center at Geita and a fifth innovation center developed. Thus the diffusion process, already obscured by numerous institutional factors, also convolutes at this regional level both hierarchical and contagious effects.

When institutions of this sort diffuse through an area, we must not forget the tremendous changes they can bring in their wake. The cooperative movement stopped unscrupulous buying practices by former cotton agents, and it provided a system of nodes from which new seeds and cultivation practices could be transmitted to the farmers. Incomes rose sharply in the area, although most of the money went for immediate consumption rather than long term, capital investment. Similar cases can be found all over the underdeveloped world. During the 1940's in eastern Nigeria, for example, small palm oil presses diffused like a forest fire through the area, and by 1953 over 3,000 were in operation. Later Pioneer Oil Mills spread equally quickly, and handled large quantities of kernels extremely efficiently. Pressed yields quadrupled the old, inefficient way of extracting oil by boiling, and the quality was also raised. Incomes went up accordingly. But the innovation had an impact far beyond the economic. Young men became rich, and tensions between generations became severe as a new class of entrepreneurs challenged the traditional bases of obedience. The women's traditional right to the hard kernels was lost when these were cracked and pressed by the mechanized mills, and many women rioted in response to the disruption in extended family organization. Thus, waves of innovation may leave behind them eddies of social change, disruption, and conflict that continue to swirl for a long time after the excitement of the initial impact is past.

The Macro-Viewpoint: Diffusion at the National and International Levels

The final shift in scale brings us to the national and international levels, where innovations may diffuse over long reaches of space and time. In past millenia, many innovations spread very slowly over a "sticky" geographic space. Despite the great technological changes of the past century, we sometimes forget the impact of new forms of transportation and communication upon diffusion rates. Furthermore, as technological innovations in transportation also spread, they speed up the diffusion of other innovations by shrinking the space in which new ideas must move. We can see this when we compare two innovations separated by millenia in time but diffusing over the same area.

Ten thousand years ago, agriculture – the simple act of planting and harvesting – was an innovation that moved slowly from a hearth area near the present-day borders of Turkey, Iraq, and Iran (Figure 56). Archaeologists, using radio-carbon dating, have

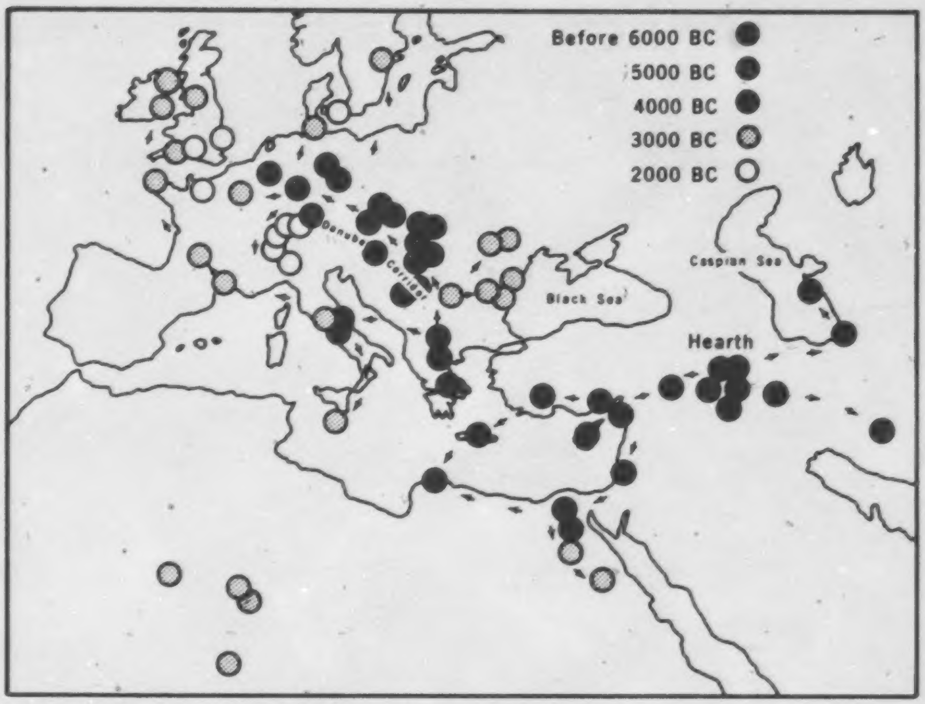


FIGURE 56. Diffusion of agriculture from radio carbon dating of archaeological sites (adapted from Clark, 1965)

determined the earliest evidences of agriculture in about 80 sites in Europe and the Middle East; and, if these dates are plotted, a very clear course of diffusion is disclosed. The earliest evidence dates agriculture at the hearth around 8650 B.C., and by 5000 B.C. the innovation had spread to Turkey and Israel, and leapt across short stretches of water to Crete and Greece. The movement highlighted a definite east-west channel, and during the next thousand years this alignment extended south to Egypt and Libya, east to the Caspian Sea, and west in a dramatic surge through the Danube and Rhine corridors. Italy also received the innovation, almost certainly across the Adriatic Sea from Greece. By 3000 B.C., the innovation had spread far and wide. The Nile provided a channel to the south, many coastal sites of northwestern Europe had agriculture by this time, and the ideas spread east to the Black Sea. Another thousand years passed, and the gaps were filled in. After six thousand years, the main diffusion wave crashed upon the British Isles—the outermost fringes of civilization.

Four millenia later, after absorbing yet another foreign innovation, Britain replied with a technological idea of her own. In 1825, the Stockton-Darlington railway line carried its first brave passengers, and by 1840 all of England's major cities were linked by steel rails (Figure 57). On the continent, the innovation pulse leapt across the channel to three innovation centers—Amsterdam, Prague, and Lyon. By 1846, the new rail lines laced western Europe, and from Russia's Window to the West, St. Petersburg (now Leningrad), a line was started to Moscow. The innovation wave continued in the fifties and sixties through Italy, Spain, southern Sweden, and eastern Europe. A bulge southeast from the early node at Prague reminds us that the Danube corridor still had a channeling effect upon human innovations 6,000 years after the agricultural

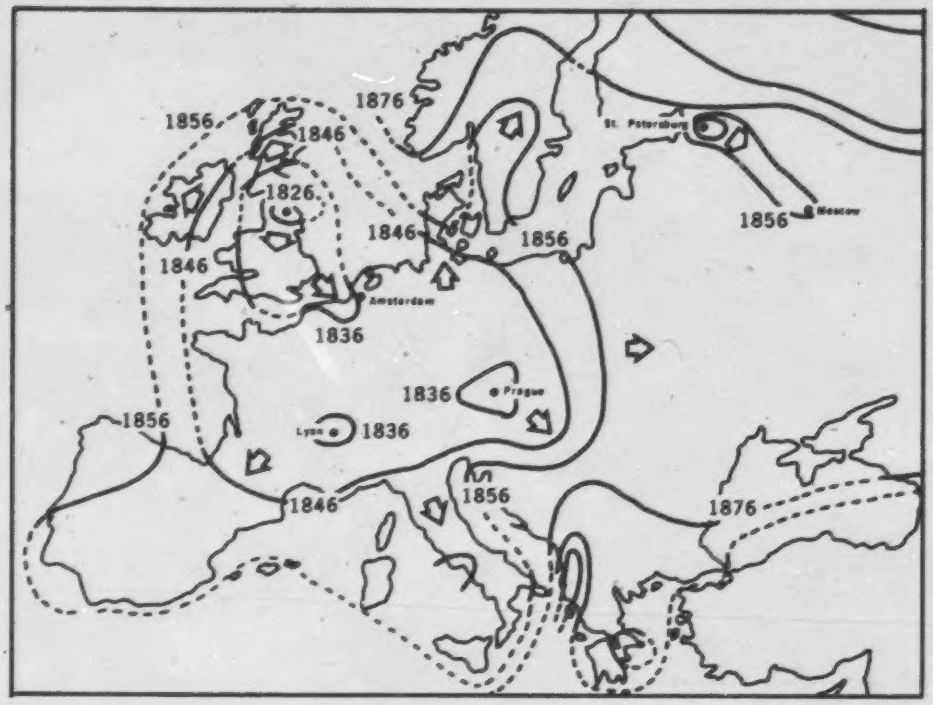


FIGURE 57. Diffusion of the railway in Europe (adapted from Gotlund, 1952)

wave surged through in the other direction.* In the seventies, Russia started its explosive rail-building program, and the pulse continued through the Balkans, Denmark, and Sweden. By the First World War, the wave had even eddied into the Albanian backwater and moved through the Middle East.

Almost by definition, the diffusion of such place-linking and space-shrinking innovations must be controlled mainly by contagion. The hierarchical influence, while discernible in the appearance of small nodes ahead of the main wave, is minimal. In the 20th century, however, the diffusion of many innovations at the international level seems to be structured much more tightly by hierarchical processes relying upon the huge, space-binding flows of information between major urban areas. The diffusion of Rotary International through Europe, for example, demonstrates the "space-hopping" influence of the central place structure, particularly in the early years before the innovation begins to seep by contagious processes from the major regional transmitting centers to their surrounding areas (Figure 58).

First started in Chicago in 1905, Rotary International by 1911 had jumped the Atlantic to Dublin and London and spread rapidly throughout the British Isles.** After the First World War, clubs in continental Europe started in the major cities close to

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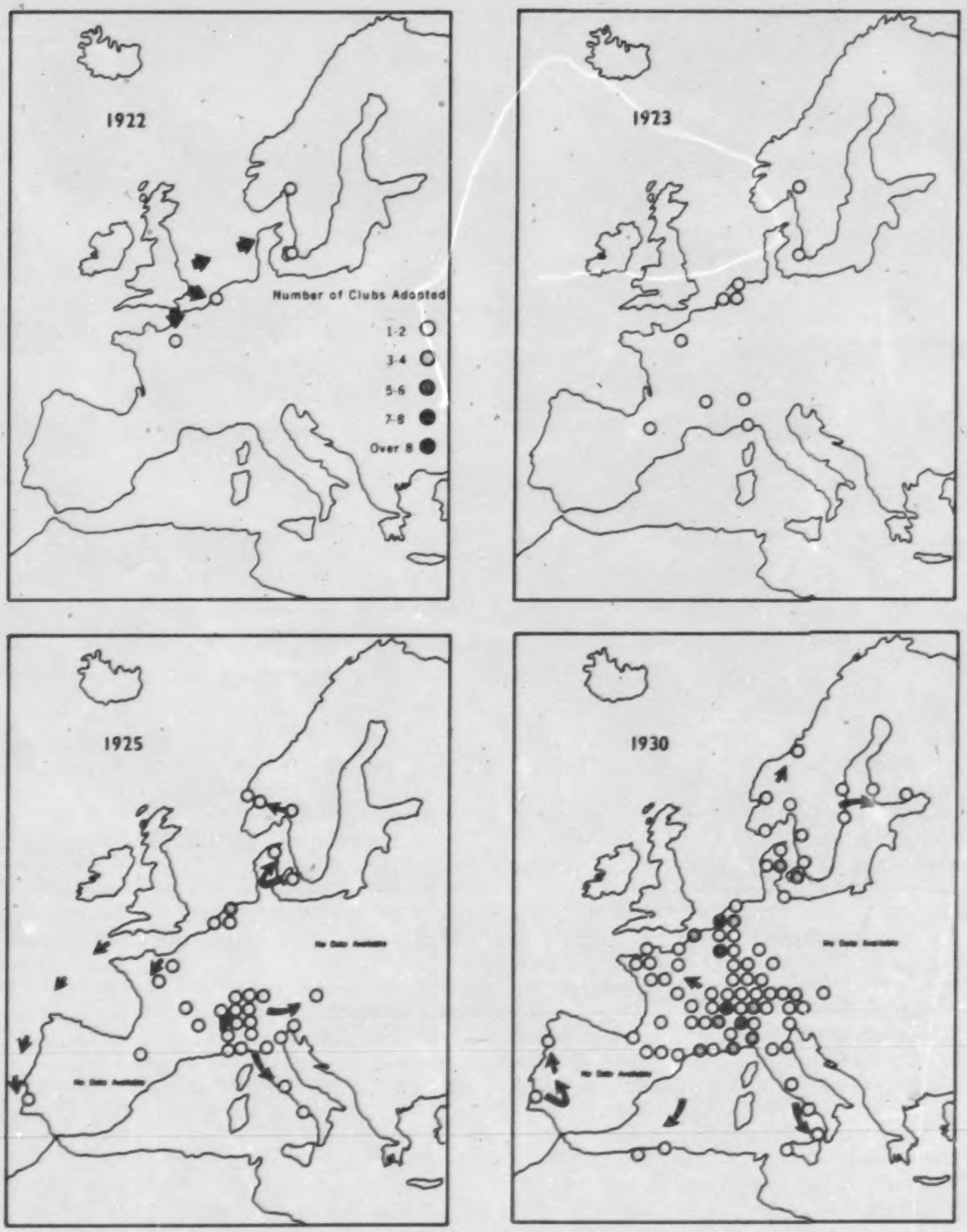
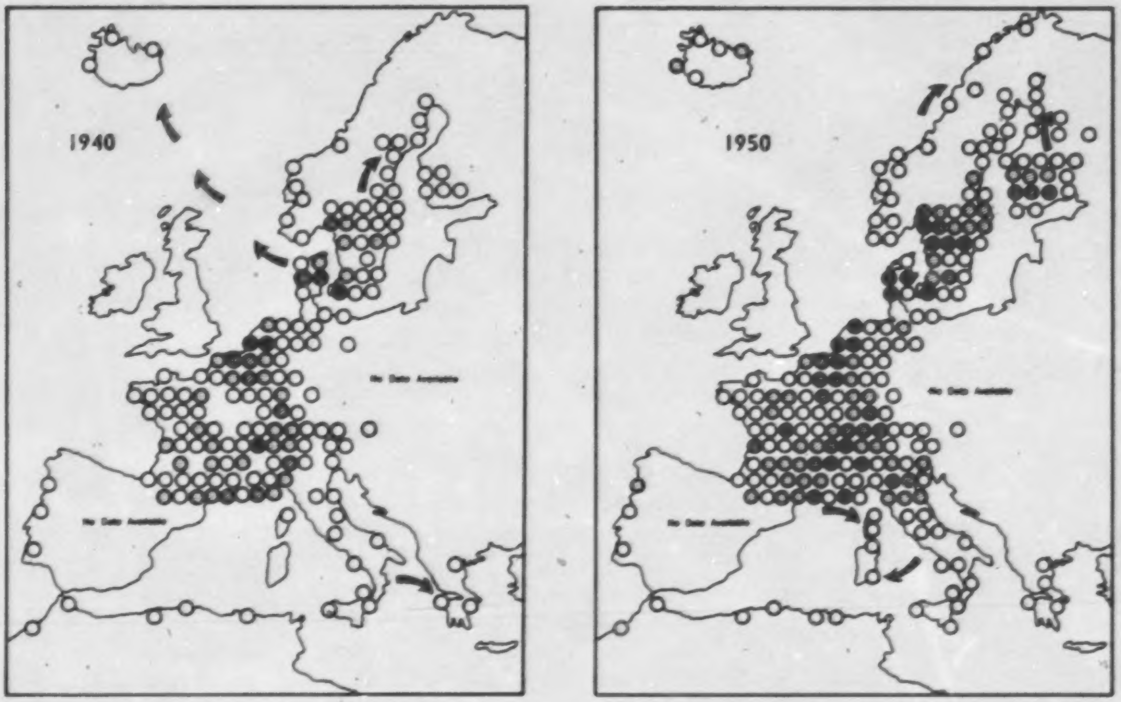
*The Danube Corridor appears as a major diffusion channel throughout history. The migration of gypsies in the 13th and 14th centuries is another example of a diffusion process controlled by this alignment: see Jean-Paul Clebert, The Gypsies (Harmondsworth: Penguin Books Ltd., 1967), pp. 23-76.

**Not shown in the map sequence.


1922
Number of Clubs Adopted
1-2
3-4
5-6
7-8
Over 8
1923
1925
No Data Available
No Data Available
1930
No Data Available
No Data Available

FIGURES 58a-d. Diffusion of Rotary Clubs (adapted from Hägerstrand, 1965)



FIGURES 58e-f. Diffusion of Rotary Clubs (adapted from Hägerstrand, 1965)

Britain, and by 1922, the national primate cities of Paris, Amsterdam, Copenhagen, and Oslo had accepted the innovation. The next year, a second node appeared in southern France and northern Italy in the large commercial centers of Genoa, Milan, Lyon, and Toulouse. In the Low Countries, around the initial entry point into the continent, the pattern thickened. Two years later, six clubs were in operation in Holland and Belgium, and the innovation diffused rapidly in Switzerland and northern Italy to form a distinct core area from which the innovation hopped down the Italian boot to Rome and Naples and east to Trieste and Vienna. Scandinavia felt the pulse from the original Copenhagen and Oslo nodes, and in a large jump a club appeared in Lisbon–undoubtedly following the strong commercial ties to England's oldest ally. By 1930, contagion was quite apparent and the crisp hierarchical patterns were blurred as the neighborhood effect took over. Dense patterns appeared in the industrial areas of Holland, Belgium, and northern Italy, and nine clubs appeared around that most international of cities–Geneva. Finland and Germany began to adopt, but the diffusion in Germany was always slow as Nazism rose and the country looked inward rather than out to an international fraternal organization. French commercial ties brought the innovation to the shores of North Africa; and Oporto, the heart of the old British port trade, adopted from Lisbon. In the next decade, contagious effects dominated and increased the density in the original core area. Only on the periphery did hierarchical effects still appear. Athens adopted and transmitted the innovation in turn to two other commercial centers in Greece; Reykjavik did the same for Iceland, receiving the pulse from Denmark. The wave was slowed by the political barrier in Germany, Austria, and Czechoslovakia, and was finally stopped by the Second World War. After the War, the organization diffused with a rush as though a dam had been broken. By 1950, dozens of clubs had appeared along a major crescent that started in Finland and ended in northern Italy, but many of the edges around the core were sharp. The Iron Curtain became an absolute barrier to the east. The relatively poor area of the Mezzogiorno of southern Italy had only a few scattered clubs, and in France the more rural, northwestern portion of the country had a similar weak pattern.

From the earlier evidence of radio broadcasting in the United States, and the diffusion of Rotary Clubs in Europe, it is clear that major urban linkages structure geographic space today, controlling the initial patterns of adoption before contagious effects take over and blur the clear hierarchical forces. Further evidence comes from the United States in the 19th century as America's embryonic urban hierarchy crystallized from the spatial flux of an earlier, and less-structured period. In the 19th century, prior to the development of immunization methods, cholera was a dreaded intestinal disease that swept across America in three great epidemic waves.

An Asian pandemic reached Europe in 1826 and, after penetrating the whole continent, crossed the Atlantic to North America in 1832. At that time, the United States was a frontier country with little structure to its urban system. Water transportation was king upon routes along the Hudson-Erie canal and the vast Ohio-Mississippi system. The epidemic started in Montreal, Quebec, and New York City, and two cholera prongs diffused along the Great Lakes and the Hudson-Mohawk valleys to meet in Ohio in July (Figure 59). From there the lake traffic carried the disease to Chicago (a town of less than 4,000!), while another prong moved rapidly down the Ohio and Mississippi Rivers to New Orleans. A third seeped down the east coast from New York, reaching Charleston, South Carolina, in late October. Size of city had virtually nothing to do with the movement, and a plot of city size against the time the cholera first appeared shows no relationship whatsoever to the urban structure. On the other hand, the timing of the epidemic's appearance is a clear function of distance from the source areas (Figure 60-A), and we can distinguish between three sets of observations depending upon the source and routeways. All indicate a clear relationship between the time of arrival and distance.

A second cholera epidemic diffused through the United States in 1849, but by this time the space was somewhat more structured by the emerging urban foci as well as the railways that were already lacing pieces of the country together. Entry again came from Europe, and New York City and New Orleans received the dread disease within nine days of one another (Figure 61). Thus two widely separated points became the transmission centers. From New Orleans, the disease swept up the Mississippi with the steam boats, forking at the Ohio-Mississippi junction only to meet again at the shore towns of Lake Erie. Two years later, cholera appeared on the Pacific, carried to Sacramento with the pioneers along the California Trail. In New York, the disease lingered during the cold winter months in the slum areas, and then burst out in the spring jumping down the hierarchy along the Hudson-Mohawk corridor and the eastern seaboard. Unlike the earlier epidemic, city size was now a clear factor in the spread of cholera (Figure 60-B). Distinguishing between the seaboard and interior cities, we see that a movement from the large cities down the hierarchy to the smaller ones is quite evident.

The last epidemic, of 1866, took place in a much more tightly structured geographic space (Figure 62), as nearly all the rapidly growing urban places were linked by railways. Movement was now much easier, particularly between the major towns and cities, and when cholera struck New York City again it trickled rapidly down the hierarchy by leaping to Detroit, Chicago, and Cincinnati. From Chicago it arrived at St. Louis, met the wave down the Ohio, and surged on to New Orleans. The effect of the

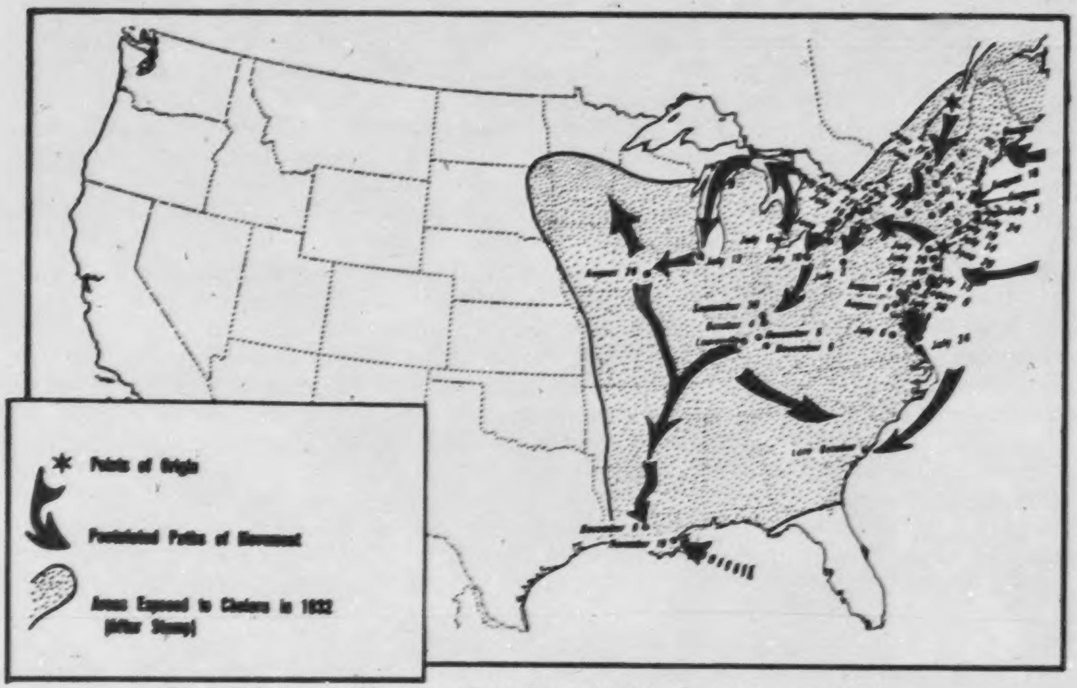

Points of Origin
Postulated Paths of Movement
Areas Exposed to Cholera in 1832
(After Stump)

FIGURE 59. Diffusion of cholera, 1832 (from Pyle, 1968)

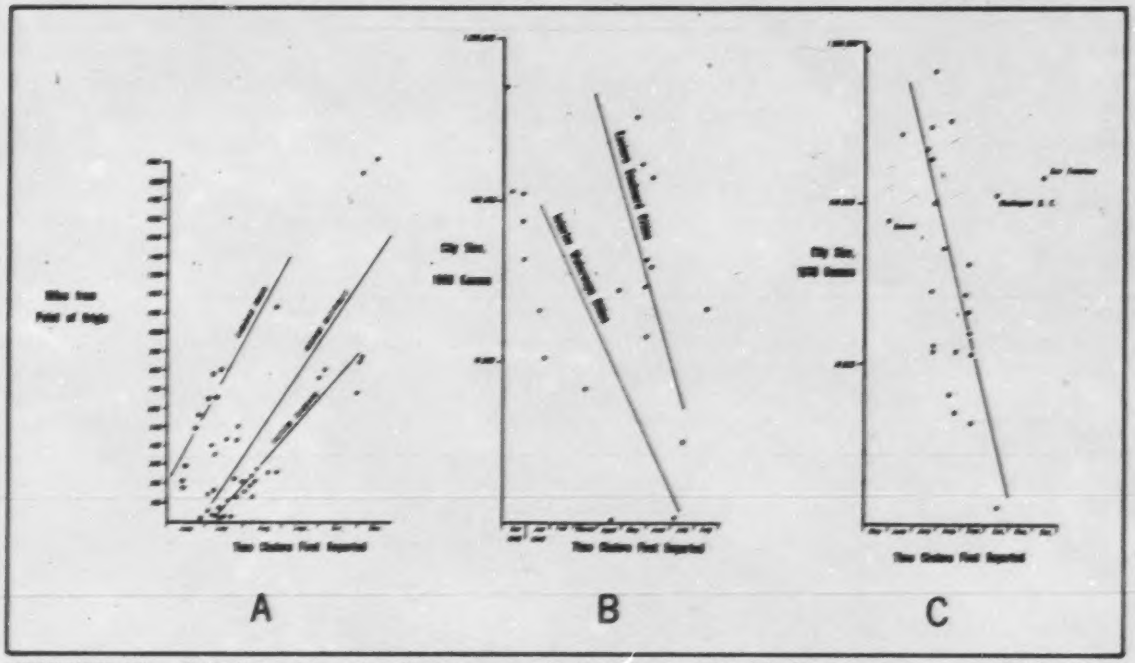


FIGURE 60. Relationships to distance and city size: (A) Cholera reports and distance from source in 1832; (B) Cholera reports and city size, 1849; (C) Cholera reports and city size, 1866 (from Pyle, 1968)

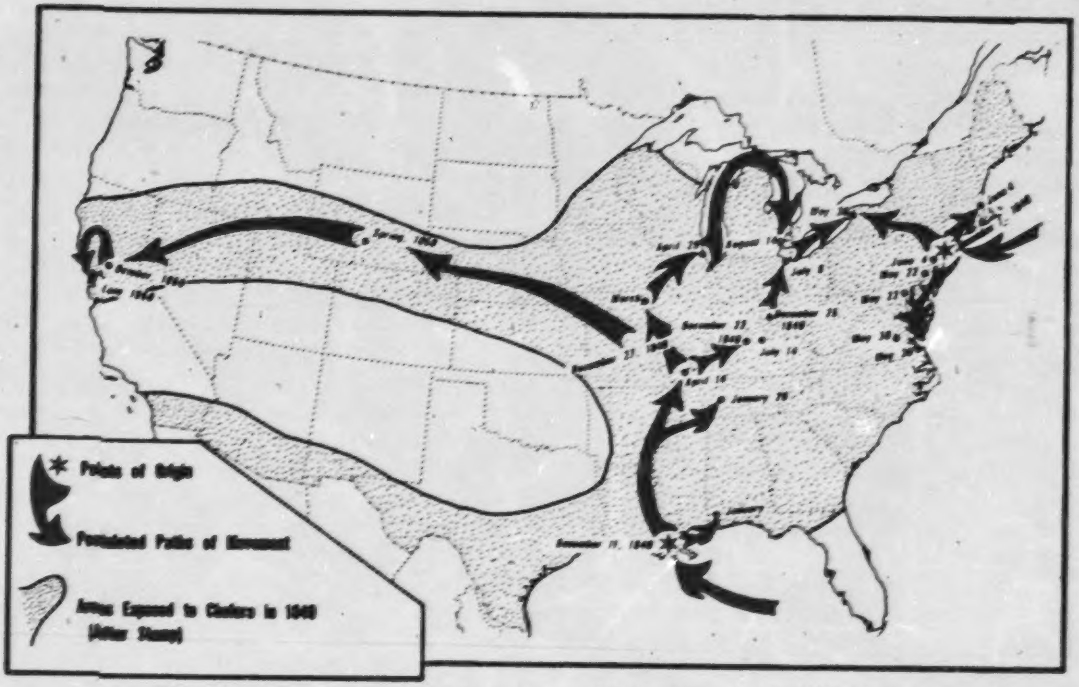

Points of Origin
Postulated Paths of Movement
Areas Exposed to Cholera in 1849 (After Stamp)

FIGURE 61. Diffusion of cholera, 1849 (from Pyle, 1968)

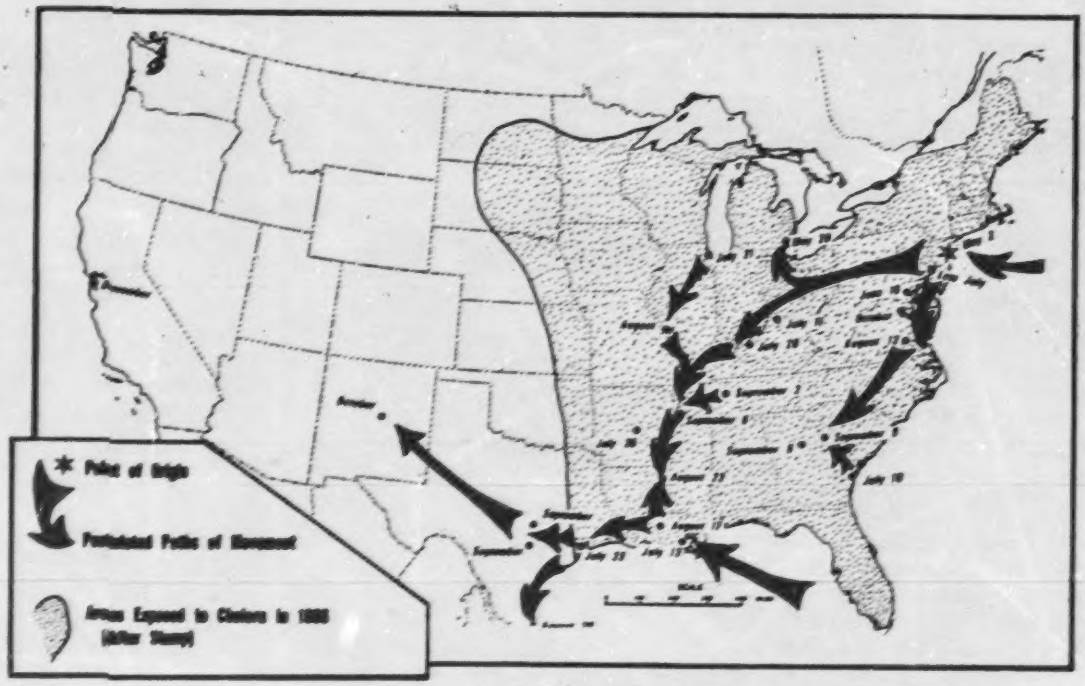

Point of Origin
Postulated Paths of Movement
Areas Exposed to Cholera in 1866 (After Stamp)

FIGURE 62. Diffusion of cholera, 1866 (from Pyle, 1968)

urban hierarchy was never more apparent (Figure 60-C), as there was a clear relationship this time to city size. Moving with the great flows of goods, people, and information from one intense concentration of human activity to another, the cities became the new transmitting nodes developing "cholera fields" that finally blanketed America.

It was not only diseases that flowed across early America. As the major alignments of urban places and transportation routes strengthened during the course of settlement, many basic functions and institutions diffused across the land. An important institution for a developing country is banking, for the location as well as mere provision of credit is an essential consideration in a development process based upon private entrepreneurial drive. Starting just after the War of Independence at Boston, New York, Philadelphia, and Baltimore, banking institutions diffused along two distinct alignments (Figure 63). By 1810, many towns on the northeastern seaboard had adopted banks, and the linear pattern split along the coastal and Fall Line towns of the South, and along the Ohio River system into Kentucky. By 1830, banking facilities had expanded considerably, moving with the tide of settlement that formed another major diffusion process from the eastern seaboard. Already an embryonic hierarchy could be seen on the eastern seaboard as many banks located in the principal cities, and major alignments appeared northward along the Connecticut and Hudson-Mohawk river valleys. The Ohio Valley alignment had also strengthened, forming a baseline for the diffusion of banks north and south with settlement into Ohio and Kentucky from Cincinnati and Louisville. On the Mississippi, river ports like St. Louis, Vicksburg, Baton Rouge, and New Orleans adopted the new economic institution, and with surging plantation agriculture as the base, more banks spread in Georgia to provide credit facilities and commercial ties to the financial hearth in the Northeast.

Ten years later, the rise of small industrial centers in the North had required a great expansion in banking, especially along the New York-Albany-Buffalo axis, where a thickening of the older patterns was most marked. The Fall Line cities formed a sharp line inland, roughly parallel to the East Coast, while farther west banking was adopted in towns settled during the previous decade from the Ohio-Mississippi axis. Finally, at the start of the Civil War in 1861, most of the new bank adoptions lay in the Midwest, especially in the areas previously swept by the frontier ten years before. A clear advancing wave was apparent also in the Southeast, as settlement advanced finally into the rugged barrier country of the Appalachians.

The overall patterns of banking adoption are not always sharp. Filling in the gaps left behind after the frontier of settlement had passed is common, and many legal problems at the state level complicated the timing of bank adoption. Furthermore, Europe, through the Bank of England, had considerable financial power during this period of American history. A depression in Europe often resulted in the calling of funds from major banks on the East Coast. These, in turn, called for funds from small banks on the frontier, many of which were quite unable to meet sudden obligations. Bank failure rates were generally high in the early years, and often soared during times of depression. Thus the diffusion waves surge and often over-extend themselves during good times, only to ebb and fail when the times are hard.

Not all the innovations of early America were financial in nature. One of the most striking aspects of the early years of the Republic was the Classic Revival, a notion that the new democracy of Washington and Jefferson embodied all the ideals and visions of ancient Greece and Rome. Its most visible expression is in the architectural styles of the 19th century, but another revealing measure is in the frequency of classical place-names given to the towns that formed as swirling eddies behind the great diffusing wave of settlement that swept across America (Figure 64).

Before 1790, only a few towns had names that tied them to the ideals of the classical world two millenia before. But then a strange thing happened. Immediately

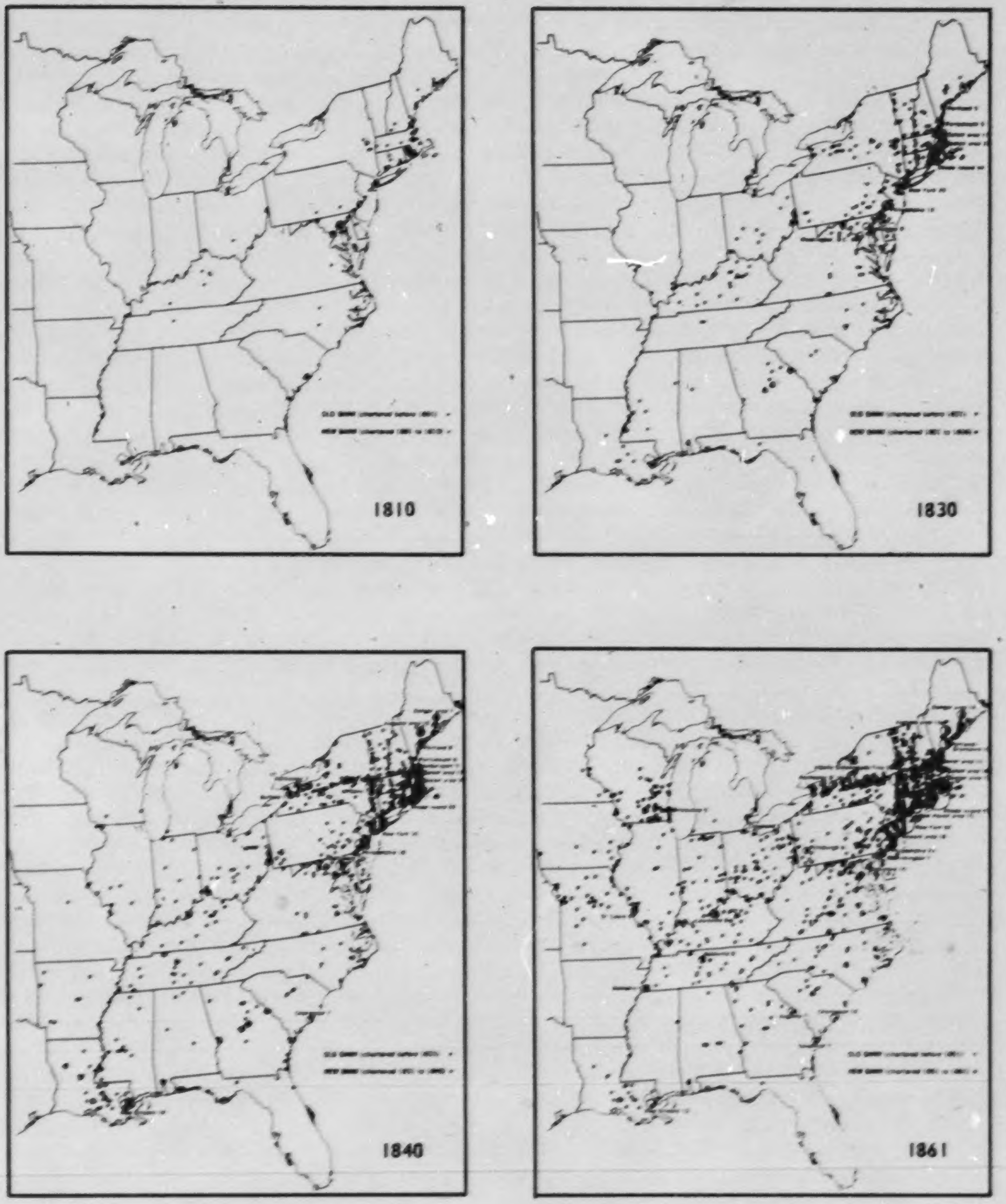

1810
1830
1840
1861

FIGURE 63. Diffusion of banking in early America (from Girling, 1968)

after the Revolution, as educated men were imbued with the highest democratic ideals, an intense node appeared in western New York State. This distinct cultural hearth was also the area of most intense architectural development of the classical style, as well as many other cultural innovations of early America. It is from this hearth area that we can trace the diffusion of classical names indicating the way in which these ancient ideals were carried by the early settlers. By 1810, the western node of New York State was still intense, and indications of the first ripple outward appeared as many of the raw, frontier towns in Ohio adopted such names as Euclid and Caesar. Three decades later (Figure 65), the wave had moved westward, with an intense node just behind the frontier in southern Michigan, and the classical ideal had diffused to the outermost fringes of settlement in the West. In the original hearth, the adoption-settlement phase was almost over. In the decade prior to the Civil War (Figure 66), the classical wave swept even further west, reaching the easternmost parts of Kansas and Nebraska and pushing north into Minnesota. Two distinct nodes appeared at the end of the California and Oregon Trails as early pioneers carried the idea to Sacramento and the Willamette Valley. These were the first outliers of a frontier that became increasingly fragmented and hollow after 1860. By 1890, the main wave was pushing into the Dakotas, and in the Southeast a sudden surge of classical naming occurred (Figure 67). But then the frontier closed, and opportunities for naming towns became increasingly rare. In the 20th century, the innovation wave carrying the classic democratic ideals dissipated and faded away.

In early America, innovation waves, quite naturally, had their origins in the eastern portion of the country. After the frontier of settlement passed, and even as it was moving through some areas, new innovations appeared in the West and moved eastward in a series of counter-diffusions. Many of the innovations involved individual rights as frontiersmen, and particularly women, chafed under archaic and undemocratic laws carried earlier from the effete and decadent East. The right of women to vote for President of the United States, for example, was first granted in Wyoming in 1869 (Figure 68). The innovation was quickly adopted by the legislators in neighboring Utah, but a quarter of a century passed before the men of contiguous Colorado and Idaho yielded. By the First World War, most of the western states had granted the right of presidential suffrage, and the diffusion eastward was evident along a main corridor of national communication through Kansas, with a leap to Illinois in 1913. World War I saw a great deal of activity by suffragettes, and if the world that emerged was "safe for democracy" many legislators thought it might also be safe for women to vote. By 1919, the suffrage wave had pushed eastward, distorted by a distinct barrier effect through the South that started in conservative New England and ended in New Mexico. It is within this intransigent belt that the nine states failing to ratify the constitutional amendment of 1920 lie. The amendment finally broke the barrier effect, and women across the land received the innovation passed into law by the more enlightened men and women of Wyoming half a century earlier.

A number of America's reform movements have sprung from the western node of innovation. Divorce laws, for example, have always been more enlightened in the West than in the East. While it is difficult to trace the diffusion of very complicated, and subtly different divorce statutes, we can use divorce rates as a surrogate measure—that is, a measure standing in for the thing we actually want to observe (Figure 69). If we take the first years in which the divorce rate exceeded 0.75 per thousand, Wyoming again appears as an innovation node, together with Washington, Oregon, and Nevada. We must remember that these states were raw lumbering country in the 1870's, and "mail-order brides" were imported by the carload! Divorce rates indicate that by 1880, the laws had eased over most of the West, although a distinct barrier effect

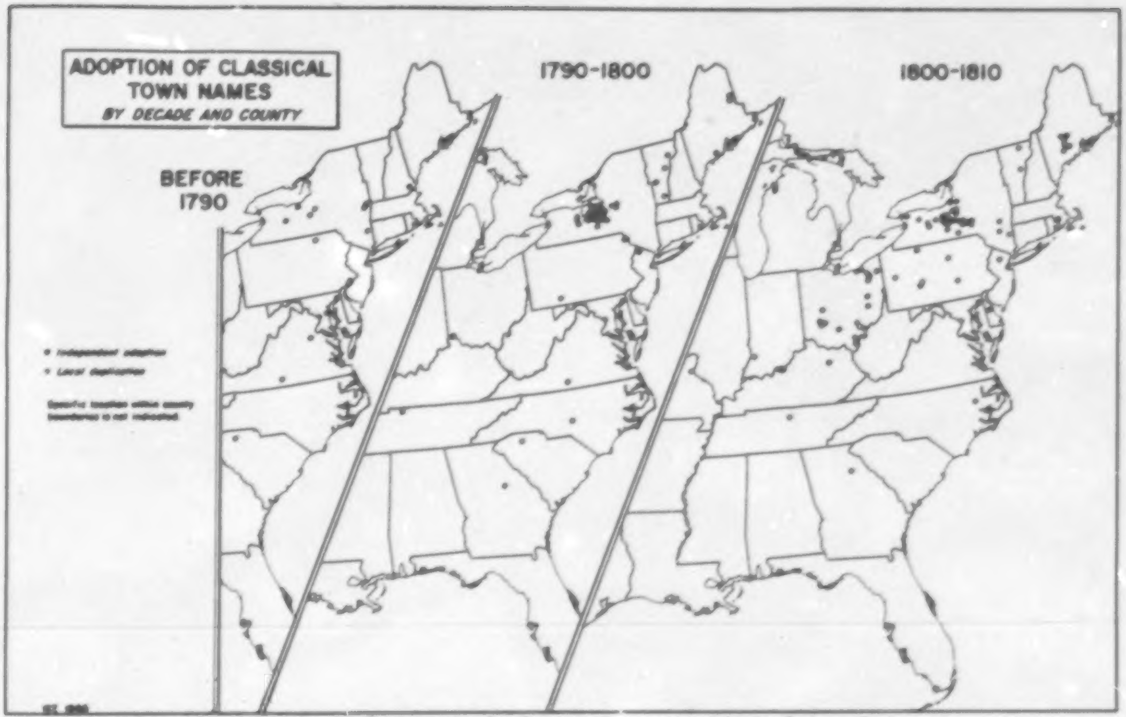

ADOPTION OF CLASSICAL TOWN NAMES
BY DECADE AND COUNTY
BEFORE 1790
1790-1800
1800-1810

FIGURE 64. Adoption of classical place names to 1810 (from Zelinsky, 1967)

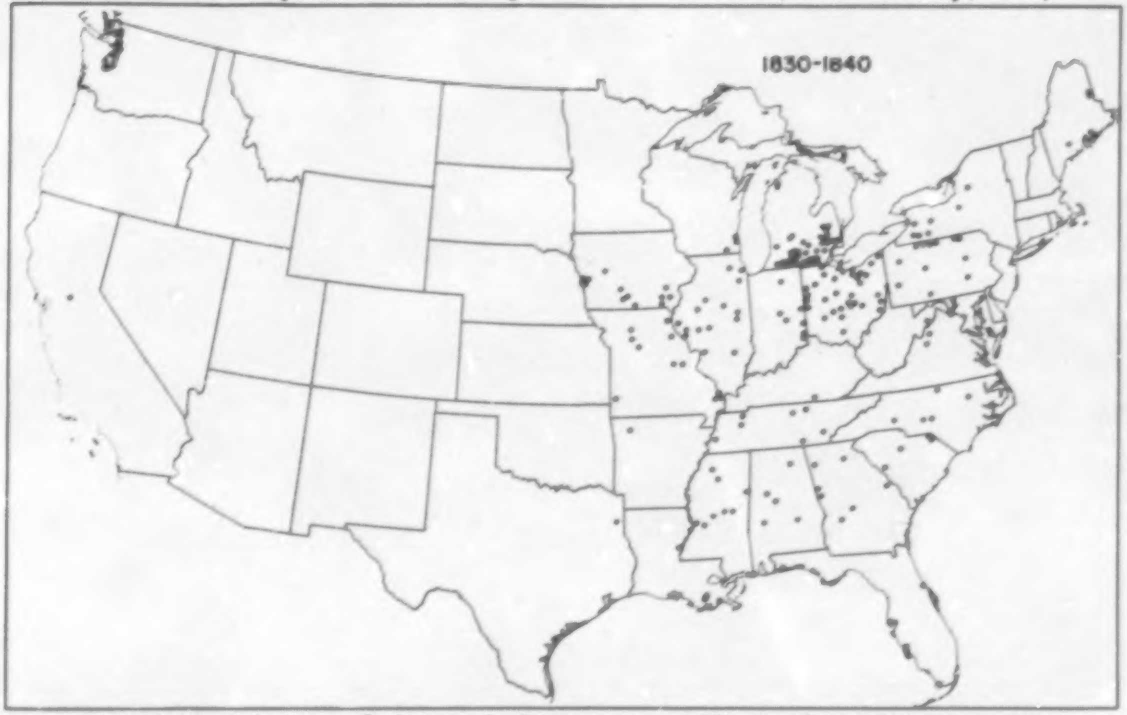


FIGURE 65. Adoption of classical place names, 1830-40 (from Zelinsky, 1967)

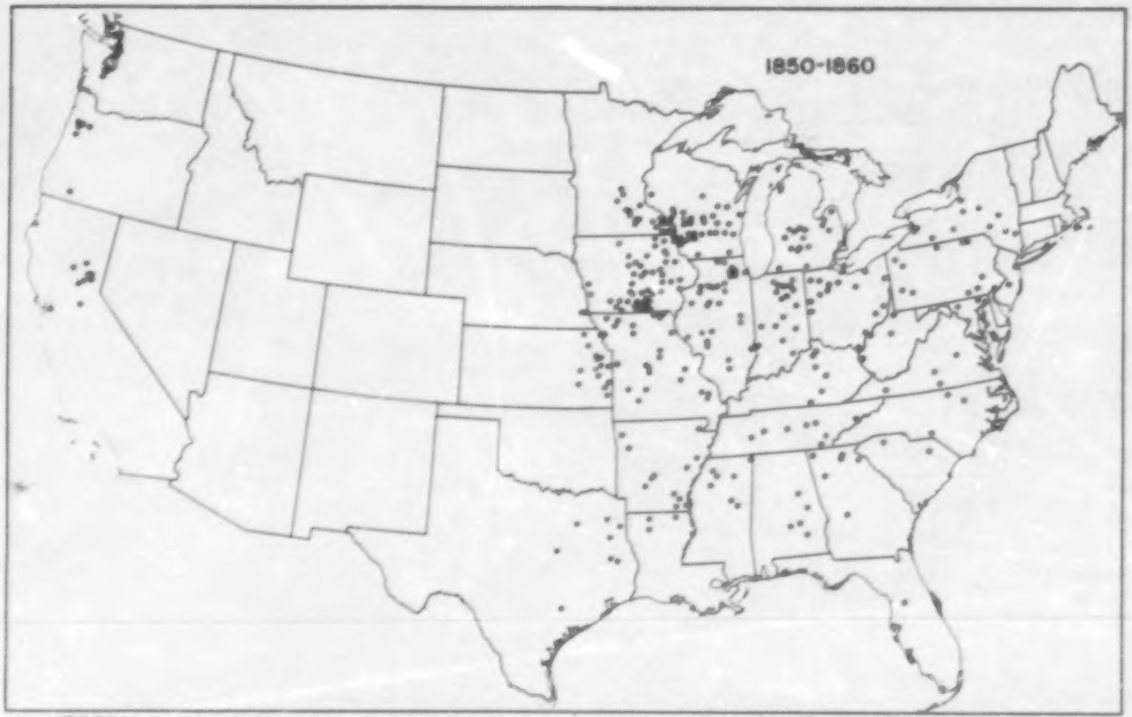


FIGURE 66. Adoption of classical place names, 1850-60 (from Zelinsky, 1967)

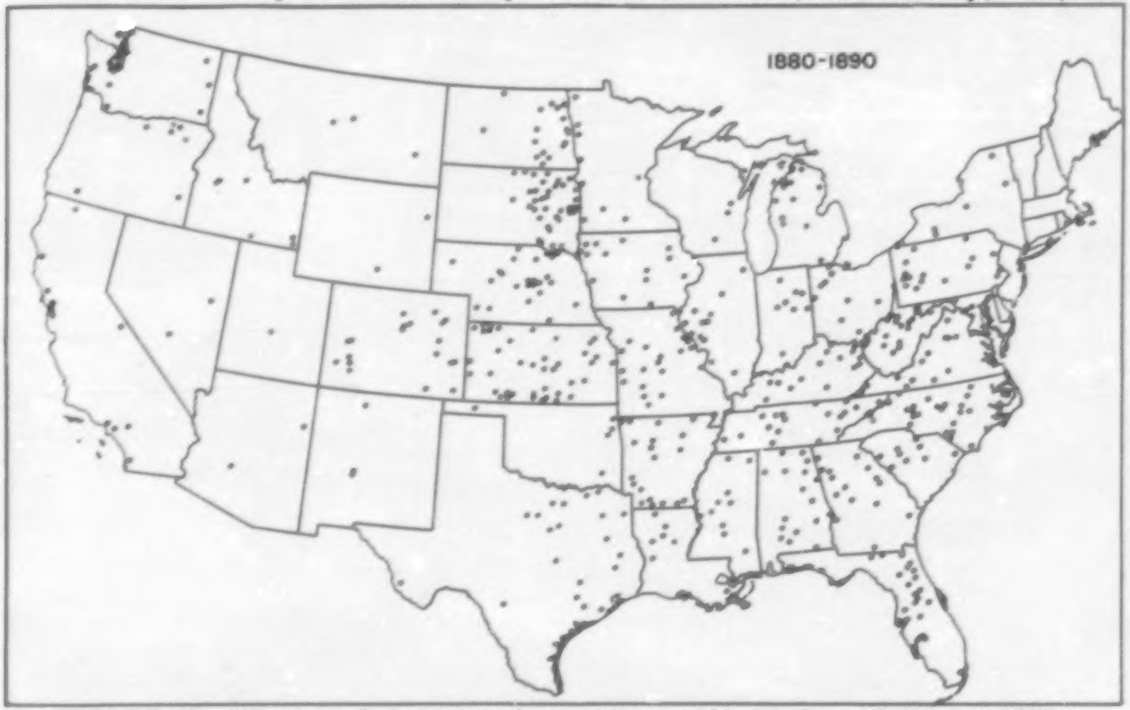


FIGURE 67. Adoption of classical place names, 1880-90 (from Zelinsky, 1967)

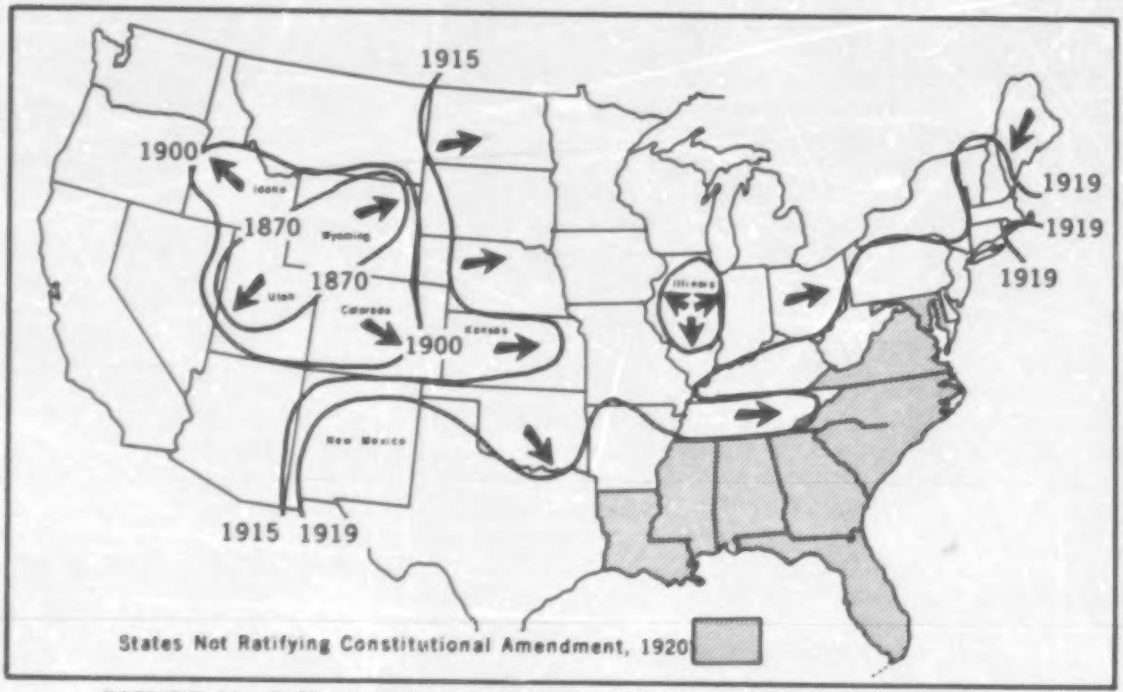

1915
1900
Idaho
1870
Wyoming
1870
Utah
Colorado
1900
Kansas
New Mexico
Illinois
1919
1919
1919
1915 1919
States Not Ratifying Constitutional Amendment, 1920

FIGURE 68. Diffusion of presidential suffrage for women, 1870-1920 (adapted from Paullin, 1932)

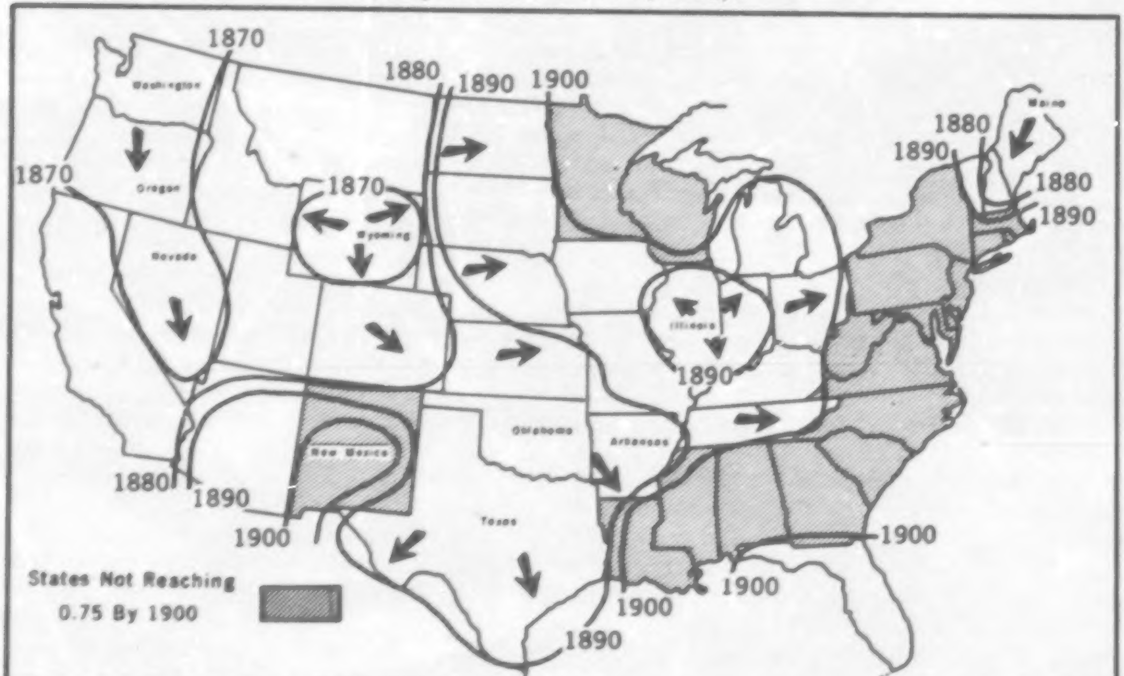

1870
Washington
1880
1890
1900
Maine
1880
1890
1880
1890
1870
Oregon
Nevada
1870
Wyoming
Illinois
1890
Oklahoma
Arkansas
New Mexico
1880
1890
1900
Texas
1900
1900
1900
1890
States Not Reaching
0.75 By 1900

FIGURE 69. Diffusion of divorce reform using the surrogate measure of the date at which rates first exceeded 0.75 per thousand

existed in Roman Catholic New Mexico. In the East a node of social enlightenment appeared in Maine and New Hampshire, but it failed to get very far as it ran into opposition from Catholic legislators in the eastern states. By 1890, rates were up in Kansas, Oklahoma, Arkansas, and Texas, and an "innovation" node appeared once again ahead of the wave in Illinois.

The two courses of diffusion from the West show strikingly similar patterns. The same nodes appear at the start of the process, and the eastern thrusts seem to match each other even to the appearance of a secondary node in Illinois. The barriers are also virtually identical, with the South resisting social and democratic reform on both occasions. We might speculate that many reform movements follow similar paths of diffusion, and that they will continue to do so in the future. Abortion reform, for example, has been passed in Colorado and is on the legislative dockets in many other western states. This reform movement may also spread along channels that seem to be very stable over time.

Many of the innovations we have observed diffusing through the United States moved at a time when America was still very much an underdeveloped country. Since most of the world is still grossly underdeveloped, and because innovation diffusion is often a vital component in any development process, our final examples are drawn from geographic studies of spatial development at the national level.

In any developing country, the provision of transportation is crucial, for without modern forms of commodity and passenger movement an economy can never reach the "take-off" stage, where the cumulative feedback process of production and investment begins. Accessibility is a necessary, though not sufficient, condition for development. It is a slippery notion, however; one of those common terms that everyone uses until faced with the problem of defining and measuring it! As a surrogate measure, we shall use the density of roads, noting the ways in which accessibility diffused through Ghana (Figure 70), the West African country with the highest annual per capita income—$150.

In 1922, large areas of total inaccessibility were divided by bridge roads that formed a rudimentary road skeleton tying the northern and southern portions of the country together. Nodes of high access only appeared in the south, usually around the major port and market towns in areas of rapidly developing cocoa production. Notice, however, the way in which the dense nodes formed core areas from which waves of accessibility moved out as feeder roads developed along the main arteries. A major exception is in the west, where the political power of the railway prevented a direct link by road parallel to the line between the port of Takoradi and the inland town of Kumasi. Five years later accessibility had diffused from the earlier core areas, squeezing the white areas with no roads into smaller pockets. The dense nodes in the south also linked as waves of cocoa farmers broke new land and joined up their new farms with short stretches of dirt roads. By 1937, and despite the crippling Depression, the south was virtually covered, and the peaks of accessibility around the cities—the growth poles of development—pushed out into the hinterlands. A few areas of the north also began to move once again, but the country was divided by a diagonal Barren Middle Zone with only a few bridgelines thrown across it. Twenty years later, this area remained one of the few with pockets of complete inaccessibility. In the south, the diffusion process continued. Very dense road networks filled the major development triangle between Accra, Kumasi, and Takoradi. The Kumasi node, which in the former period threw outliers of high accessibility ahead of the main advancing wave to the west, caught up and coalesced with them.

The diffusion sequence of changing accessibility reminds us again of the development of a photographic plate. The "latent image" of Ghana's space economy in 1958 can be traced through the intervening periods to the patterns of more than a quarter

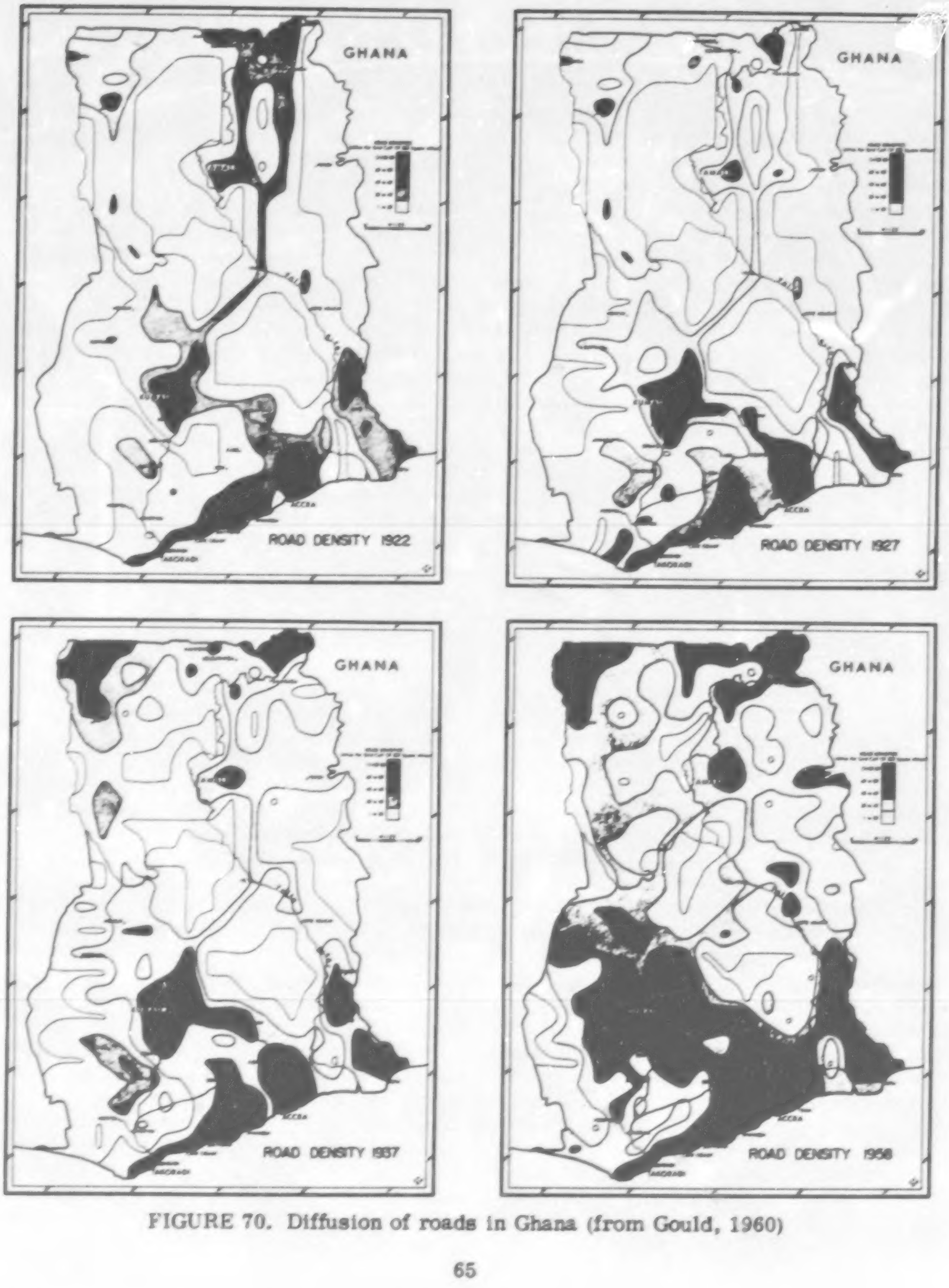

GHANA
ROAD DENSITY 1922
ACCRA
TAKORADI
GHANA
ROAD DENSITY 1927
ACCRA
TAKORADI
GHANA
ROAD DENSITY 1937
ACCRA
TAKORADI
GHANA
ROAD DENSITY 1958
ACCRA
TAKORADI

FIGURE 70. Diffusion of roads in Ghana (from Gould, 1960)

of a century before. Given a blank map for 1970, it would not be difficult for you to sketch the next pattern, extending the sequence of the past to predict the future. But think, for a moment, what this means. Your ability to predict spatial pattern (and you will probably be very close to the mark), implies that you have some intuitive model about the diffusion process in the furthermost reaches of your mind! The difficulty is getting your intuitions crystallized out and onto paper in the form of rules whose validity can be tested as rigorously as possible. The process of modeling is not always an easy one.

Our final example of diffusion at the national level comes from another West African country, Sierra Leone, which also experienced the development and modernizing influences of British colonial rule during the first six decades of the 20th century. In our concern for development, we are inclined to concentrate upon economic innovations and measures, forgetting sometimes that development must also take place along a series of political, educational, and social dimensions if the total process is to be successful. Thus an important innovation is the political one of local government and administration, which allows an increasingly large number of people to participate in local affairs and small-scale development schemes. A new system of local government was not imposed upon the 140 chiefdoms of Sierra Leone by the colonial administration, but was allowed to diffuse from two core areas. The final decision to adopt local government ordinances lay with the people.

If we return to the notion of our three-dimensional graph with space and time coordinates, and plot each small chiefdom as a point whose location is determined by latitude, longitude, and time of adoption, we can fit an increasingly complex series of diffusion surfaces (Figure 71). The first time-space surface is a plane, which indicates that the simplest and most general trend is from the coast inland (A). As we allow the surface to warp, first two (B) then three (C) and finally four times (D), it fits the scatter of chiefdoms ever more closely. Thus the final surface (D) filters out all the local anomalies and noise and indicates the smoothed and general trend of the diffusion process. From the eastern and western core areas of model chiefdoms the innovation of local administration spread rapidly through the area where the demonstration effect was strongest, and where the news could be carried quickly by people traveling over the main railway line that forms a major axis of development in the country. From this east-west alignment the idea diffused south, until by 1945 nearly every chiefdom had adopted the innovation. In the strongly Moslem and more conservative North, resistance was much greater except for a sudden thrust that used a branch of the railway as a main line of penetration. Thus the relationshiop between diffusing innovations and the underlying structure of the transportation network is strong and critical. Accessibility must itself diffuse, and only then can innovations flow over the accessibility surface formed by the roads and railways that structure the space through which new ideas must move.

When we use the term modernization, we invoke a composite image of many social, economic, and political developments moving together, changing the minds of men as well as the human landscape. In Sierra Leone, summary indices of this most complex process have been devised to measure the spatial variation in modernization across the country (Figure 72). Using trend surfaces again to filter major national patterns from the local effects, the simple plane of modernization slopes gently from the coast towards the interior (A). Allowing the plane to bend (B), discloses the wedge effect of the railway slicing the country into two parts along the east-west axis, while more complicated warpings (C) show the build-up of modernization in the capital city on the coast (within the 50 isoline). Notice particularly the way the developing surface of modernization parallels the diffusion surface of local government administration, indicating that this overall, composite surface tightly structures the national space that controls in turn the way new ideas and innovations move. Interestingly, if the chiefdoms lying far above this last modernization surface are plotted (D), the rudimentary urban hierarchy of Sierra Leone is highlighted. Thus, we end with a convoluted process that can be decomposed into hierarchical and regional components, in the same way that diffusion processes themselves can be characterized in hierarchical and contagious terms.

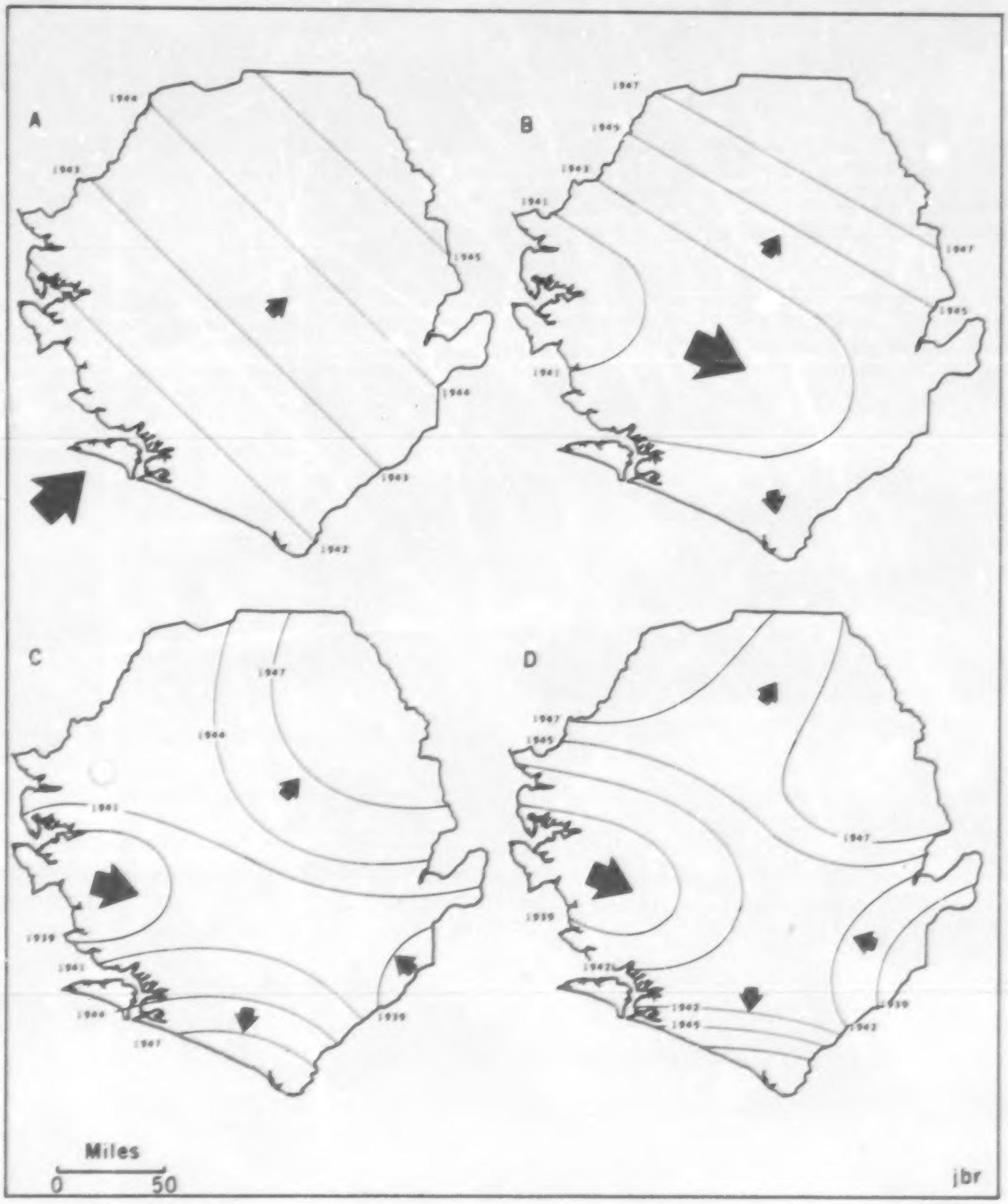
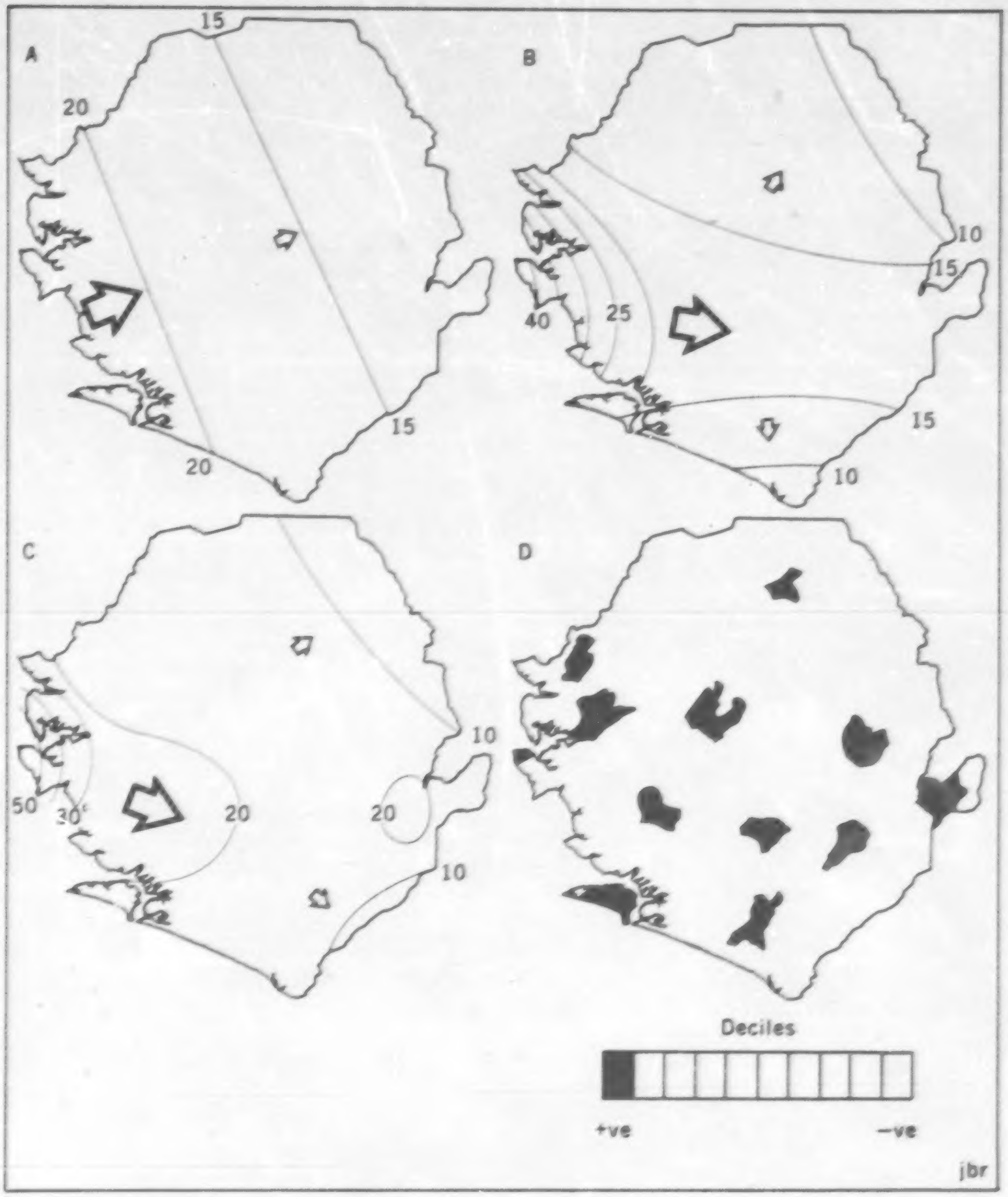


FIGURE 71. Diffusion of native administration in Sierra Leone (from Riddell, 1969)



A
15
20
15
20
B
10
15
40
25
15
10
C
10
50
30
20
20
10
D
Deciles
+ve
−ve
jbr

FIGURE 72. Diffusion and development of the modernization surface in Sierra Leone (from Riddell, 1969)

IV. The Frontiers of Diffusion Research

And now you are on your own. If you choose to work one day in the area of diffusion processes you will find a rich and challenging field, for our ignorance exceeds our knowledge many times! The links between spatial and other aspects of human behavior are only now being forged, as geographers and other members of the human sciences link hands and work together on clusters of problems that cannot be solved by men within the narrow focus of traditional academic fields. The models far down the cones of resolution must be linked across the fields, even as within geography itself much effort is needed to develop and tie together the few useful abstractions we possess. Our ability to model diffusion processes at the regional and national levels is very slight, in part because of severe data problems that were compounded until very recently by the lack of large and fast computing facilities. This barrier has now been broken, but the barrier of human thought and intellect remains.

At the applied and empirical levels there is also much to do, although the links between application and theory must never be weakened. First, because theory building and empirical testing are complementary processes; second, because there is nothing so applicable as good theory! But when field studies are undertaken without a strong background of theory, and when theory develops divorced from the world, profundity is likely to fly out of the window. Many future applications of the theory of spatial diffusion will have strong humanitarian overtones, for if we can gain a thorough understanding of these spacio-temporal processes our ability to advise is greatly magnified. What are the crucial* points to tap in a network of social communication to maximize the diffusion rate? What are the poles of spatial accessibility into which we can plug new ideas, medicines, and innovations in a poor but developing country? How stable are the main channels over time?

Perhaps you would like to answer some of these questions yourself.

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*Remember that the root of crucial is crux–a cross. Crossing points in a network represent places where decisions may be made. To increase the rate at which things diffuse through the network, we need to know much more about these "spatial decision" points.

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